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ABSTRACT

This publication is a resource guide designed primarly as an aid to the instructor. All of the experiments contained in the Mechanical Engineering Laboratory Manual have been successfully completed under laboratory conditions by both staff and students. The results of these experiments have been computed and are presented in this publication. The presentation includes raw data, sample calculations, curves generated from results and selected computer programs. A section of the guide contains a detailed list of materials and equipment needed for the construction and operation of each experiment. The current purchase price (whenever possible), and the vendors are also included. This information, along with appropriate sketches, should be of assistance in determining the budget needed to develop a laboratory program similar to that presented in the Mechanical Engineering Laboratory Manual. (Author/GA)

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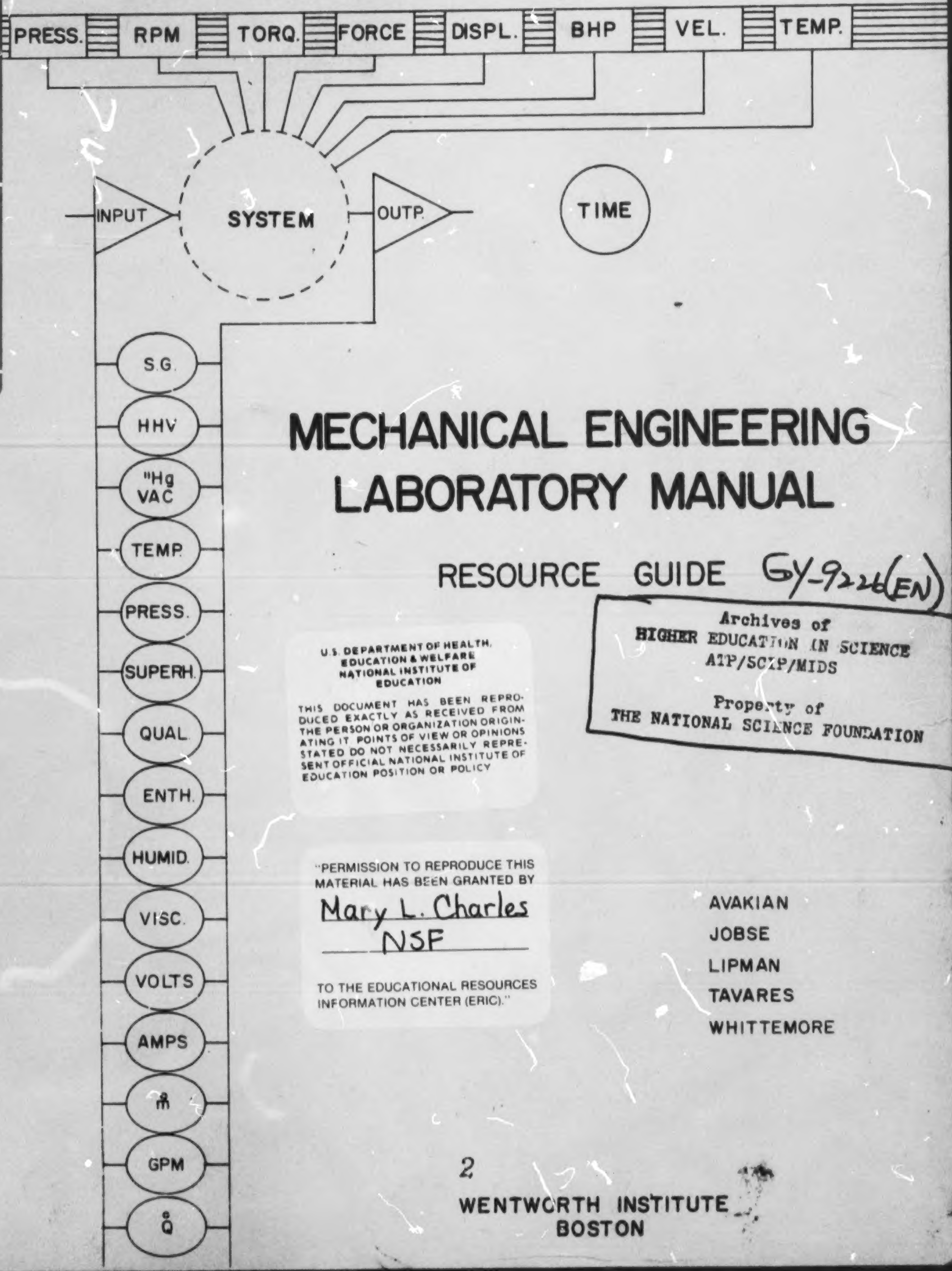
PRESS.
RPM
TORQ.
FORCE
DISPL.
BHP
VEL.
TEMP.
INPUT
SYSTEM
OUTP.
TIME
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HHV
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TEMP.
PRESS.
SUPERH.
QUAL.
ENTH.
HUMID.
VISC.
VOLTS
AMPS
$\dot{m}$
GPM
$\dot{Q}$

MECHANICAL ENGINEERING LABORATORY MANUAL

RESOURCE GUIDE

GY-9226(EN)

Archives of
HIGHER EDUCATION IN SCIENCE
ATP/SCIP/MIDS

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WENTWORTH INSTITUTE
BOSTON

SE 028 543

WENTWORTH INSTITUTE

Resource Guide
for
Mechanical Engineering Laboratory Manual

Prepared by

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March 1974

The resource guide is designed primarily as an aid to the instructor. All of the experiments contained in the Mechanical Engineering Laboratory Manual have been successfully executed under laboratory conditions by both staff and students. The results of these experiments have been computed and are presented in the resource guide. The presentation includes raw data, sample calculations, curves generated from results and selected computer programs.

A section of the guide contains a detailed list of materials and equipment needed for the construction and operation of each experiment. The current purchase price, (whenever possible) and the vendors are also included. This information, along with appropriate sketches, should be of assistance in determining the budget needed to develop a laboratory program similar to that presented in the Mechanical Engineering Laboratory Manual.

MATERIALS LIST

and

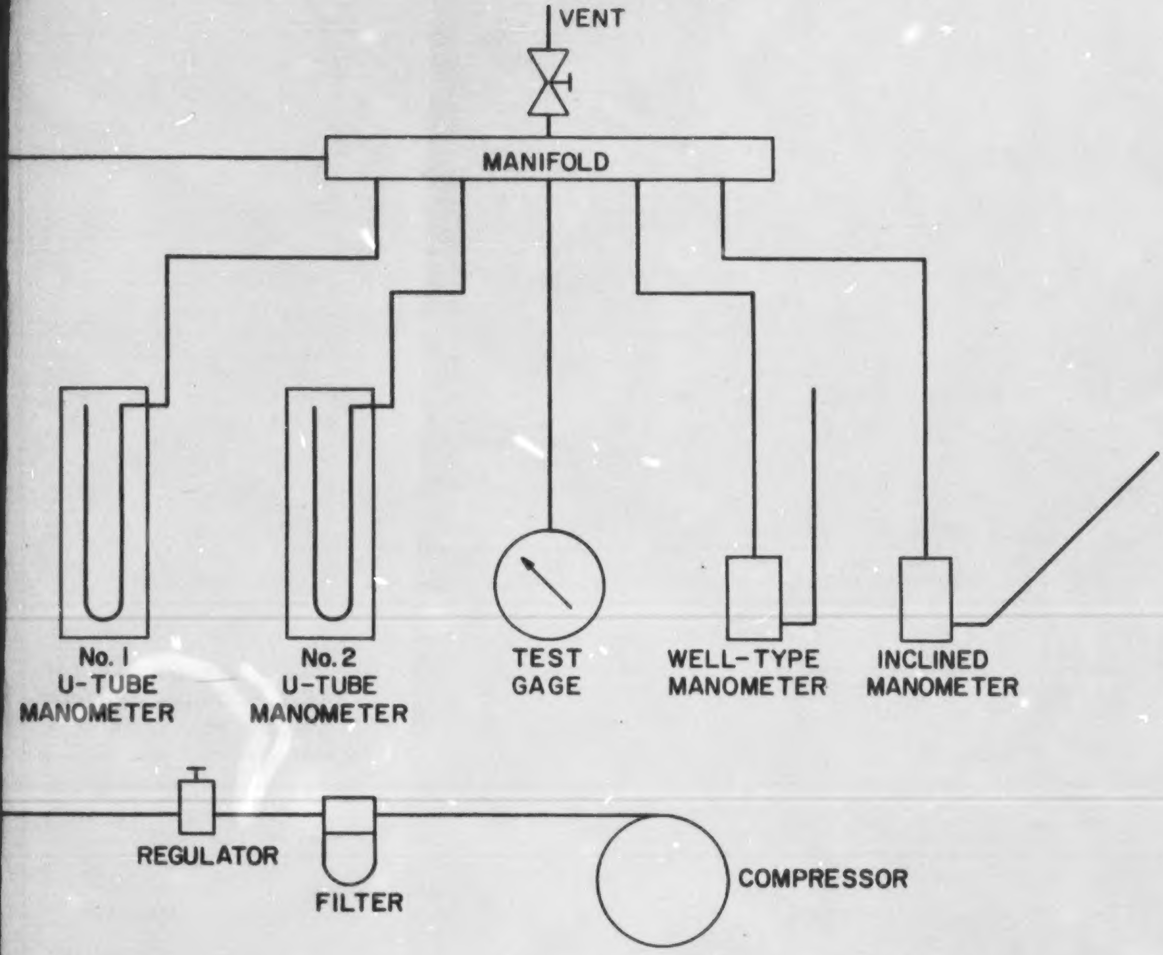
EQUIPMENT SKETCHES

EXPERIMENT - 2 PRESSURE MEASUREMENTS APPROXIMATE TOTAL COST $280

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
2 Leveling Bottles	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 458 of cat. #71,#40-460 with tubulator for rubber tubing connection, capacity 175 ml	$6.45 each
Acco Helicoid Test Gage	American Chain & Cable Co. Acco Helicoid Gage Division 929 Connecticut Avenue Bridgeport, Conn. 06602 Local Distributor Peeco Inc. 79 Prospect Street Sommerville, Mass. 02143 (617) MO6-4444-5-6	Pg. 20 of helicoid gages cat. HG-57 4 1/2 in. W, range 0 - 15 Psi, Figure intervals 1 psi, subdivisions 0.05 psi, acaloy flanged case, accuracy 1/4 of 1% of scale range.	$55.50
Gast Lubricated Air Compressor	Gast Manufacturing Corp. Box 97 Benton Harbor, Mich. 49022 616-926-6171 Local istributor Peeco Inc. 79 Prospect Street Sommerville, Mass. 02143 (617) MO6-4444-5-6	Pg. 16 of cat. #120-100 Model 0211-103A-G8C with inlet and outlet filter, 1/6 HP, 115-60-1 motor, 1725 RPM.	$87

EXPERIMENT - 2 PRESSURE MEASUREMENTS

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
3 - U-Tube Manometers Mercury	The Meriam Instrument Co. 10920 Madison Avenue Cleveland, Ohio 44102 Local IWT Corp. 186 Crest Road POB 36 Needham, Mass. 02194 (617) 444-3632	Pg.4 of cat. #200 Model 10 AA 25 WM (wall mounting type) range 20" (10-0-10), figure intervals 1", subdivision 0.1".	$24/per manometer Approximately $10 mercury per manometer
2 - Steel Rules 24" & 36" long	Best Source of 1 inch interval 0.1 in sub. rules OR L.S. Starrett Athol, Mass. 01331 (617) 249-3551	Pg. 128-129 of Starrett catalog No. 27 24" catalog No.C306R 36" catalog No.C606R	$10 - $15


VENT
MANIFOLD
No. 1 U-TUBE MANOMETER
No. 2 U-TUBE MANOMETER
TEST GAGE
WELL-TYPE MANOMETER
INCLINED MANOMETER
REGULATOR
FILTER
COMPRESSOR

PRESSURE MEASUREMENT SYSTEM

EXPERIMENT - 3 AREA MEASUREMENT APPROXIMATE TOTAL COST $313

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Precision Balance	SciChemCo	Pg. 23 of catalog 71, AL-SI-CO utility analytical balance # 2-444, 200 gram capacity, 0.1 MG sensitivity	$219
Polar Planimeter	Keuffel & Esser Co. Morristown, NJ 07960 Local B. L. Makepeace, Inc. 1266 Boylston Street Boston, Mass. 02215 (617) 267-2700	Pg. 21 of Keuffel & Esser catalog # 8 # 62 0000 tracer lens,0.01 sq. inch vernier unit, Keuffel & Esser compensating polar planimeter	$94.00 each

EXPERIMENT - 4 TEMPERATURE MEASUREMENT APPROXIMATE TOTAL COST $450

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
2-0 to 220 Total Immersion Thermometer	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 914 of catalog #71, #79-737-02, 0 to 230°F, 2° Division, 305mm length	$3.60 each
1-Vapor Filled Thermometer	Republic Pipe and Electric Supply Corporation Charles Street Somerville, Mass. (617) 628-5050	Pg. 185 of catalog #B-1, Trerice Dial Thermometer, vapor actuated, 30 to 240°F range, #V80035 back flange, bottom connection	$37
Copper - Constantan Thermocouple Wire	Leeds & Northrup Co. North Wales, Penn. 19454 Local Leeds & Northrup Co. 875 Providence Highway Dedham, Mass. 02026 (617) 326-8816	Pg. B-35 of Leeds & Northrup, catalog #H0.0001-A 573 copper and constantan (38) (type T), wire number 20-55-1-A (20Awg)	$0.14/foot $28/200 Ft. roll
1-Portable Potentiometer	Leeds & Northrup Co. 875 Providence Highway Boston, Mass. (617) 326-8816	Pg. J-12 of Leeds & Northrup catalog # H0.0001-A573 Model No. 8696-2 double range 0-22 and 20-64MV	$322
1-Safety Beaker 3000 ml capacity	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 55 of catalog #71, #5-204 Pyrex safety beaker with handle and spout	$13.26
Hot Plate	SciChemCo	Pg. 502 of catalog # 71, # 42-832 thermolyne type 1900, 120 volts AC, 750 watts	$35.75

EXPERIMENT - 5 SPECIFIC GRAVITY MEASUREMENT APPROXIMATE TOTAL COST $180

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Westphal Specific Gravity Balance	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 33 of catalog # 71, # 2-732 Read directly to the fourth decimal place. Includes cylinder, riders, forceps, plummet	$79
6-Westphal Balance Cylinders	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 33 of catalog # 71, # 2-738	$2.75 each
6-Hydrometer Cylinders	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 271 of catalog # 71, # 28-395 Kimax heavy glass with hexagonal base and pourout. 300 MM length, 50 MM diameter	$4.35 each
5-API plain Hydrometers	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 521 of catalog # 71 API plain form. Solid metal ballast. Approximate length 163 MM subdivisions 0.5 1 # 48-414 Range 10-30 1 # 48-416 Range 20-40 1 # 48-418 Range 30-50 1 # 48-421 Range 40-60 1 # 48-452 Range 5-11	$4.20 each

EXPERIMENT - 5 SPECIFIC GRAVITY MEASUREMENT

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
6-SG Hydrometers ASTM	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 517 of catalog # 71 Length 260 MM, 0.001 subdivisions 1 # 47-518 Range 0.750-0.800 1 # 47-520 Range 0.800-0.850 1 # 47-521 Range 0.850-0.900 1 # 47-522 Range 0.900-0.950 1 # 47-523 Range 0.950-1.000 1 # 47-524 Range 1.000-1.050	$5.20 each

EXPERIMENT - 6 SPEED MEASUREMENT APPROXIMATE TOTAL COST $650

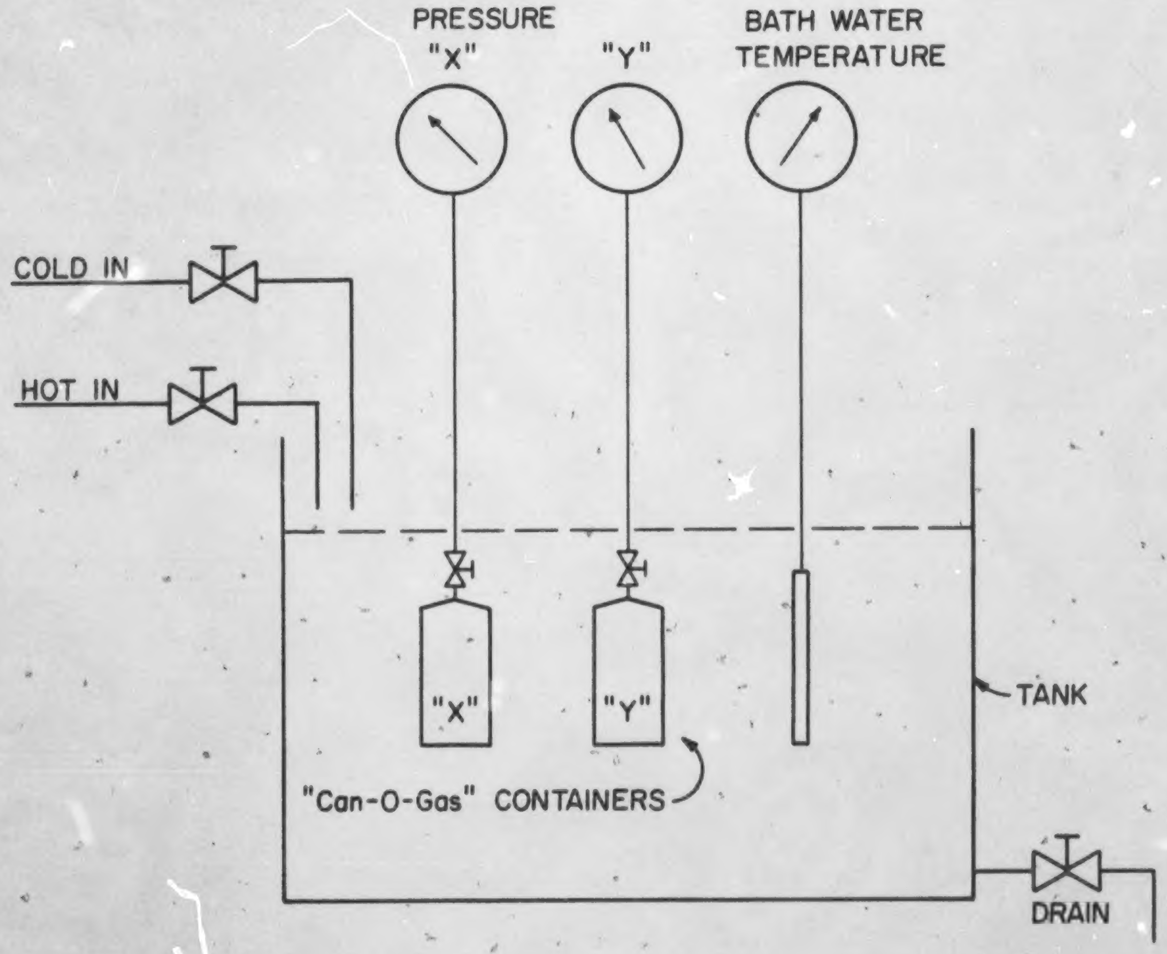
EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Strobotac	General Radio Co. 22 Baker Avenue West Concord, Mass. 01781 (617) 646-0550	Type 1531 - AB, 100-25000 RPM in three ranges	$380
Hand Tachometer	James G. Biddle Co. Township Line & Jolly Road Plymouth Meeting, PA 19462 (21) 69200 Local Mancib Co. 21A Street Middlesex Turnpike Burlington, Mass. (617) 272-9450	Jagabi Tachometer Catalog #554, five ranges RPM 30 to 120, 100 to 400, 300 to 1200, 1000 to 4000, 3000 to 12000	$126
Revolution Counter	L.S. Starrett Company Athol, Mass. 01331 (617) 249-3551	Pg. 257 of Starrett catalog no. 27, Model no. 107 with steel tip and two rubber tips, 0 - 5000 revolutions, includes case	$14.40
Stop Watch	Best Source		$12
Motor	Electro Sales CO., Inc. 100 Fellsway West Somerville, Mass. 02145 (617) 666-0500	Pg. 30 of Electo Sales catalog no. 72-3 Bodine type NSH-33, shunt wound motor model #277, 1/20 HP, 115 volts DC	$41.79
Converter	Electro Sales Co., Inc. 100 Fellsway West Somerville, Mass. 02145	Pg. 47-48 of Electro Sales catalog no. 72-3, Bodine model no. 903 type ASH 400, 1/20 HP	$68.66

EXPERIMENT - 7A PRESSURE - TEMPERATURE RELATIONS APPROXIMATE TOTAL COST $270

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
2000 ml Erlenmeyer Flask	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg 383 catalog #71, #35-691-01 Erlenmeyer, narrow mouth, reinforced top, Kimax flask	$4.29
Vacuum Pump	SciChemCo	Pg 784 catalog #71, #72-732-01 Welch Duo-Seal vacuum pump, 25 liters/min, 115v, 60 cycle, 0.1 millitorr model R-1400	$207
Thermometer	SciChemCo	Pg. 914 catalog #71, #79-757-02 0 to 230°F, 76MM Immersion, 305 MM length	$3.60
Vacuum Gage	Republic Pipe & Electric Supply Corporation	Pg. 183 catalog #B-1, #501S U.S. vacuum gage 0-30" Hg, 3 1/2" diameter dial	$5.65
Hot Plate	SEE EXPERIMENT ON TEMPERATURE		$35.75
Valve Manifold	A. E. Borden Co., Inc. 184 Everett Street Allston, Mass. 02134	Pg. 93 catalog I72, Robinair CMN-3 charging and testing manifold, w/o gages	$6.95
Charging Lines (2)	A. E. Borden	Pg. 94 catalog I72, Robinair CH-36E-1Y, 36" length	$2.75 each

EXPERIMENT - 7B PRESSURE - TEMPERATURE RELATIONS APPROXIMATE TOTAL COST $70

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Can of R-12	A. E. Borden Co. Inc. 184 Everett Street Allston, Mass. 02134 (617) 787-0900	Pg. 90 catalog I 72 15 oz. can - 0 - gas Freon 12, Virginia Chemicals	$2.25
Can of R-22	A. E. Borden	Pg. 90 catalog I 72, 1 lb. can - 0 - gas Freon 22, Virginia Chemicals	$3.00
Temperature Gage	A. E. Borden	Pg. 75 catalog I 72, #203-231 Marsh remote reading thermometer type 57-DFPR-B/B 40 to 140 range, 3 1/2 in. dial	$23.18
Pressure Gages	A. E. Borden	Pg. 74 catalog I 72, 1- #023441 2 1/2", 30'' x 300 lb. type 3-DP Marsh Standard Compound Gage 1- # 023523 2 1/2", 0 to 500 lb. type 1-DP Marsh Standard Press. Gage	$4.29 $3.52
15 gal tank with bottom drain	Best Source		$25
Imperial Tap - A - Can Valve (2)	A. E. Borden	Pg. 59 catalog I 72, #330C Valve for male spud screw top cans	$1.75 each


PRESSURE
"X"
"Y"
BATH WATER
TEMPERATURE
COLD IN
HOT IN
"X"
"Y"
TANK
"Can-O-Gas" CONTAINERS
DRAIN

REFRIGERANT PRESSURE-TEMPERATURE APPARATUS

The following equipment are part of the general set up for the following experiments.

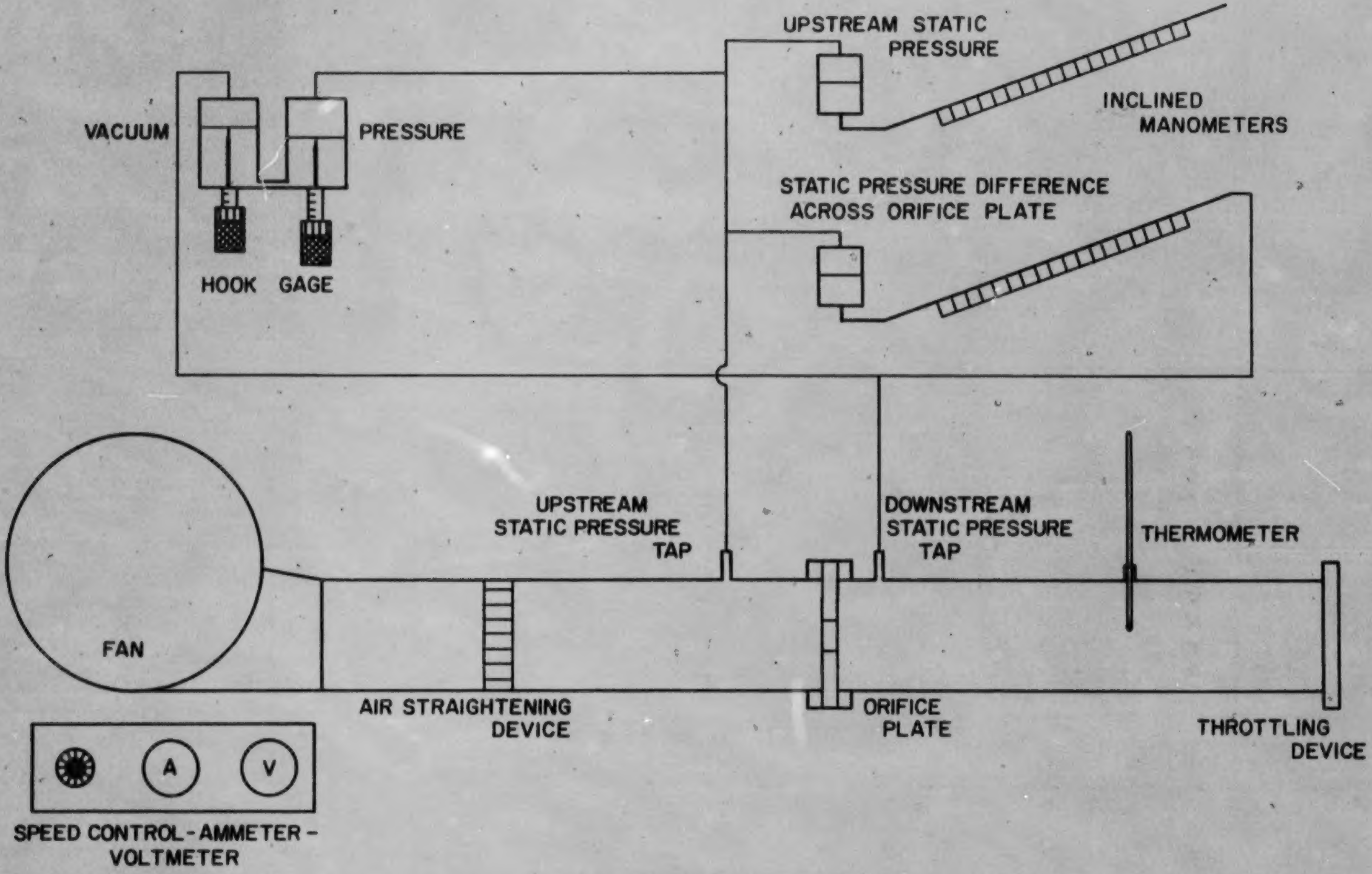
Exp. No. 8 Calibration of inclined manometer
Exp. No. 9 Velocity measurement
Exp. No. 11 Velocity Profile
Exp. No. 15 Fan testing and performance
Exp. No. 16 Fan Laws

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Direct current Ammeter	Simpson Electric Company 5200 West Kinzie Street Chicago, Illinois 60644 (312) 379-1121	Pg. 6 bulletin No. 2079 of Simpson Electric Co., Model # 29 range 0-5 AMP, 4 1/2" case, catalog # 0490, ± 2% accuracy	$19.65
Direct Current Voltmeter	Simpson Electric Company Local Paul R. Sturgeon Co., Inc. 1330 Boylston Street Local phone (617) 734-7710	Pg. 6 bulletin No. 2079 of Simpson Electric Co., Model # 29, range 0-150 volt, 4 1/2" case catalog # 7720, ± 2 % accuracy	$20.70
2 Pitot static tubes	United Sensor & Control Corp. 85 School Street Watertown, Mass. 02172 (617) 926-1000	United Sensor Catalog bulletin P-1, Model # PAC-8KL, fixed take-offs, attached mounting chuck, 1/8 in. sensing stem diameter, 8 in. probe length	$19. 75 each
A) Duct exit throttling - device with various positions B) Orifice plate C) Flanges D) Straighteners E) Manometer Reservoirs F) Glass & flexible tubing	Various sources available for material. All items can be produced in machine shop. Local Hub Stamping & Elec. Co. 314 West Second Street Boston, Mass. 02127 (617) AN8-1900		Approximate cost of material - $30

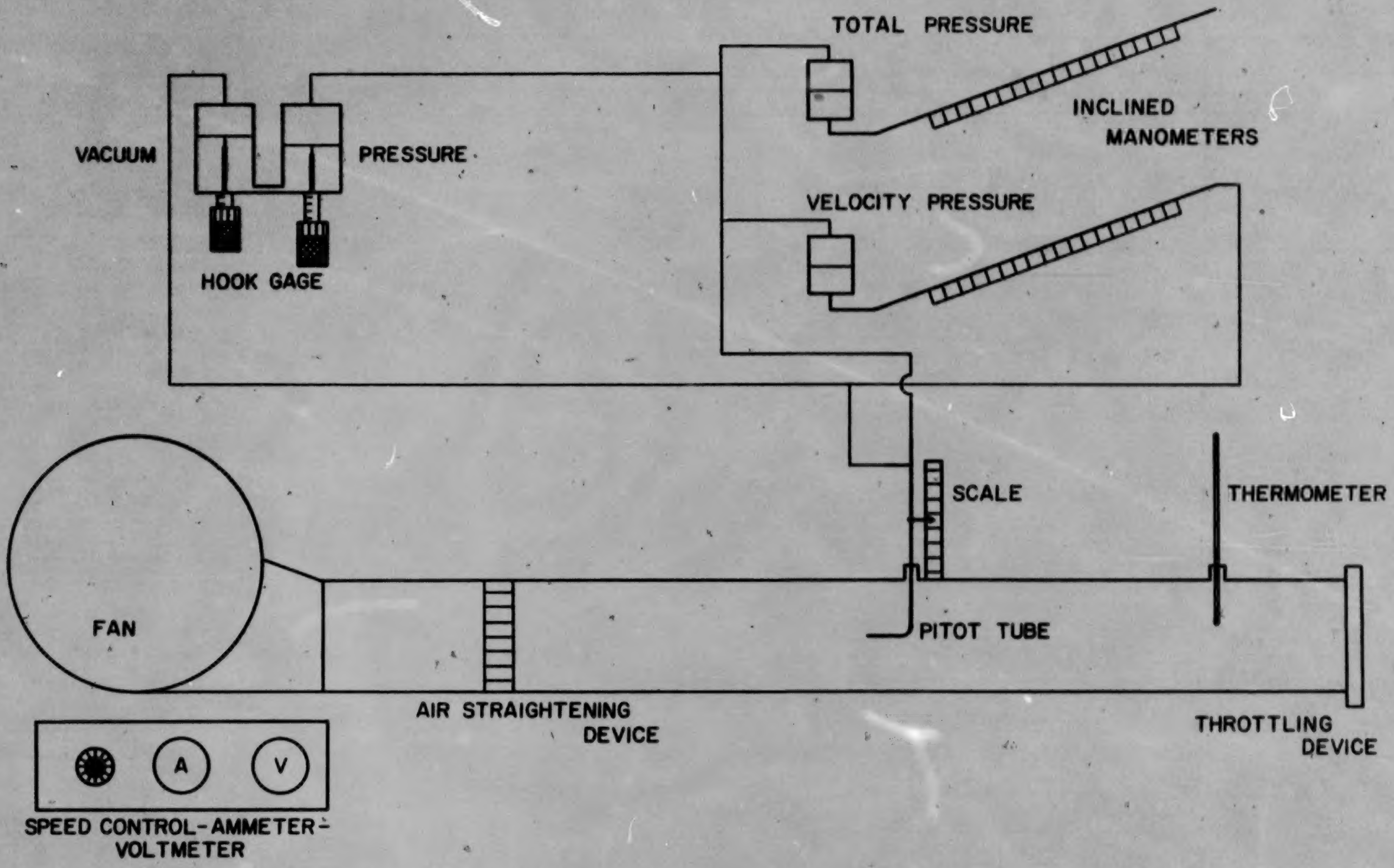
The following equipment are part of the general set up for the following experiments.

Exp. No. 8 Calibration of inclined manometer
Exp. No. 9 Velocity measurement
Exp. No. 11 Velocity profile
Exp. No. 15 Fan testing and performance
Exp. No. 16 Fan Laws

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
4 steel rules 2 - 12" long 2 - 24" long	Best source of 1 in. intervals 0.1 in. sub. rules or L.S. Starret Company Athol, Mass. 01331 (617) 249-3551	Pg. 127-128 of Starret catalog # 27 12" catalog # C306R, 24" catalog # C606R	$20
Thermometer	SciChemCo Local 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 914 of catalog # 71, range - 30 to 120°F, 1° divisions. 305 MM length. Catalog # 79-757-01	$3.60


UPSTREAM STATIC PRESSURE
INCLINED MANOMETERS
VACUUM
PRESSURE
HOOK GAGE
STATIC PRESSURE DIFFERENCE ACROSS ORIFICE PLATE
UPSTREAM STATIC PRESSURE TAP
DOWNSTREAM STATIC PRESSURE TAP
THERMOMETER
FAN
AIR STRAIGHTENING DEVICE
ORIFICE PLATE
THROTTLING DEVICE
A
V
SPEED CONTROL - AMMETER - VOLTMETER

FAN TEST APPARATUS WITH ORIFICE PLATE
(Adhere to Standard Test Code)


TOTAL PRESSURE
INCLINED MANOMETERS
VACUUM
PRESSURE
VELOCITY PRESSURE
HOOK GAGE
SCALE
THERMOMETER
FAN
PITOT TUBE
AIR STRAIGHTENING DEVICE
THROTTLING DEVICE
A
V
SPEED CONTROL-AMMETER-VOLTMETER

FAN TEST APPARATUS WITH PITOT TUBE
(Adhere to Standard Test Code)

The following equipment are part of the general set up for the following experiments.

Exp. No. 8 Calibration of inclined manometer
Exp. No. 9 Velocity measurement
Exp. No. 11 Velocity profile
Exp. No. 15 Fan testing and performance
Exp. No. 16 Fan Laws

APPROXIMATE TOTAL COST $430

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
D8C peerless blower with motor	Central Fan Co. 284 Broadway Cambridge, Mass. 02139 (617) 547-3581	Pg. 18 of catalog, No. 22, 115V, 1/4 HP DC, 1750 RPM, counterclockwise rotation, bottom horizontal discharge (CCW-BH)	$144
Transition piece for D8C peerless blower to 5.75" outlet	Best source Local William and Poor Elm Street Cambridge, Mass.		$25
Minarik Control Model # M-35 & line cord	Minarik Electric Co. Los Angeles, CA 90013 Local Electro Sales Co., Inc. 100 Fellsway West Somerville, Mass. 02145 (617) 666-0500	Pg. 111 of catalog No. 72-3, Model # M-35, for 1/4 HP shunt or PM motors, armature 90 VDC @ 3.5 AMP input, 115 volts, AC and DC output	$108
Transparent Duct - 2 pieces - 5 ft.length each	Best source Local Hub Stamping & Engraving Co. 314 West Second Street Boston, Mass. 02127 (617) AN8-1900	Pg. 17 Hub catalog Cadco cast acrylic resin tube. 5.75" ID 6.00" OD	$39/10 ft.

EXPERIMENT - 8 CALIBRATION OF INCLINED MANOMETER

APPROXIMATE TOTAL COST $120

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Dwyer Hook Gage	Dwyer Instruments, Inc. Highway 212 at 12 P.O. Box 373 Michigan City, IND 46360 Telephone (219) 872-9141 Local, E. Clark & Associates 19 Whittier Drive Acton, Mass. 01720 Telephone (617) 263-579	Pg. 14 of Bulletin D-40 of 1972 Dwyer catalog Model No. 1420 0-2" full scale range, 0.001" divisions 0.001" accuracy	$120

EXPERIMENT - 9 VELOCITY MEASUREMENT APPROXIMATE TOTAL COST $560

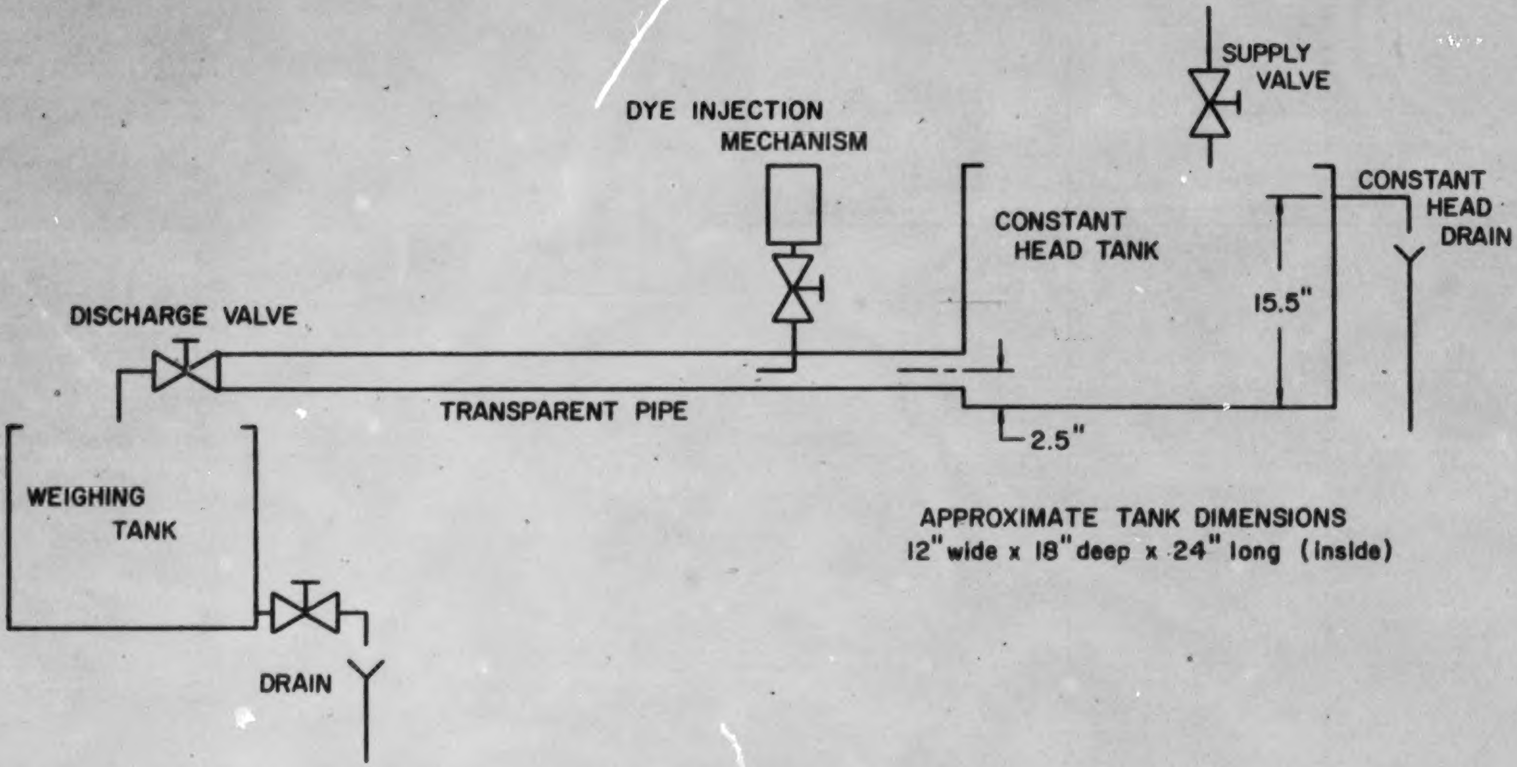
EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Alnor Velometer all purpose set 6000AP	Alnor Instrument Co. 420 N. La Salle Street Chicago, Illinois 60610 (312) 467-1331 Local Osgood Engineering Co. 500 Maple Street Hathorne, (Danvers) Mass. 01937 (617) 933-4744	Alnor all purpose set 6000 AP. This set is suitable for work in industrial ventilation, heating and air conditioning fields. Complete set consists of: 1) 6006AP velometer (seven scales; 0-300, 0-1250, 0-2500, 0-5000, 0-10,000 F.P.M. and 0-1; 0-10 in of H_2O) 2) 6030CP range selector (0-1250 or 0-2500 F.P.M. and 0-1 in. of water) 3) 6030DP range selector (0-5000 or 0-10,000 F.P.M. and 0-10 in. of water) 4) 6050P Lo-flow probe (0-300 F.P.M.) 5) 6060P pitot probe (12 in. long) 6) 6070P diffuser probe 7) 6080AP static press probe (0-10 in. of water) 8) 6080CP static press probe (0-1 in. of water) 9) 2-2161 single rubber 10) 1010 carrying case	$371.80
Dwyer Air Meter	Dwyer Instruments Inc. Highway 212 at 12 P.O. Box 373 Michigan City, IND 46360 (219) 872-9141 Local E. Clark & Associates 19 Whittier Drive Acton, Mass. 01720 (617) 263-5759	Pg. 9 of bulletin H-100 of 1972 Dwyer catalog Model No. 460 measures air velocity in a range of 260 - 4000 FPM, and static pressures 0.005" -1.0" of water	$15

EXPERIMENT - 9 VELOCITY MEASUREMENT

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Davis Anemometer	Davis Instrument Manufacturing Co. Inc. 513 East 36th Street Baltimore Maryland 21218 Local Charles T. Morgan Co. 500 Maple Street Danvers, Massachusetts (617) 774-3215	Biram type A/2 - 4" range 100 - 5000 F.P.M.	$ 166 *Includes aluminum case and extension handles

EXPERIMENT - 10A REYNOLDS NUMBER APPROXIMATE TOTAL COST $120

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Constant Head Tank	4' x 4.5' sheet obtained from	2 pieces of 24 3/4" x 18" 2 pieces of 12" x 18" 1 piece of 24 3/4" x 12 3/4" } 1 sheet 4' x 4.5' 3/8" thickness Shop Fabricated	$40
1" ID transparent tubing	Best Source Local Hub Stamping & Elec. 314 West Second Street Boston, Mass. 02127 (617) AN8-1900	5 - 10 feet long	$10
Needle Valve	Best Source		$10
Dye Reservoir Hyperdermic Needle Plastic Medical tubing Control Valve for Dye Supply	Best source		$10
Weighing Tank - 50 lb. capacity	Best source		$30
Stop Watch	Best source		$12
Scale	Can be set up using platform scale and weighing tank of experiment No. 12.		—

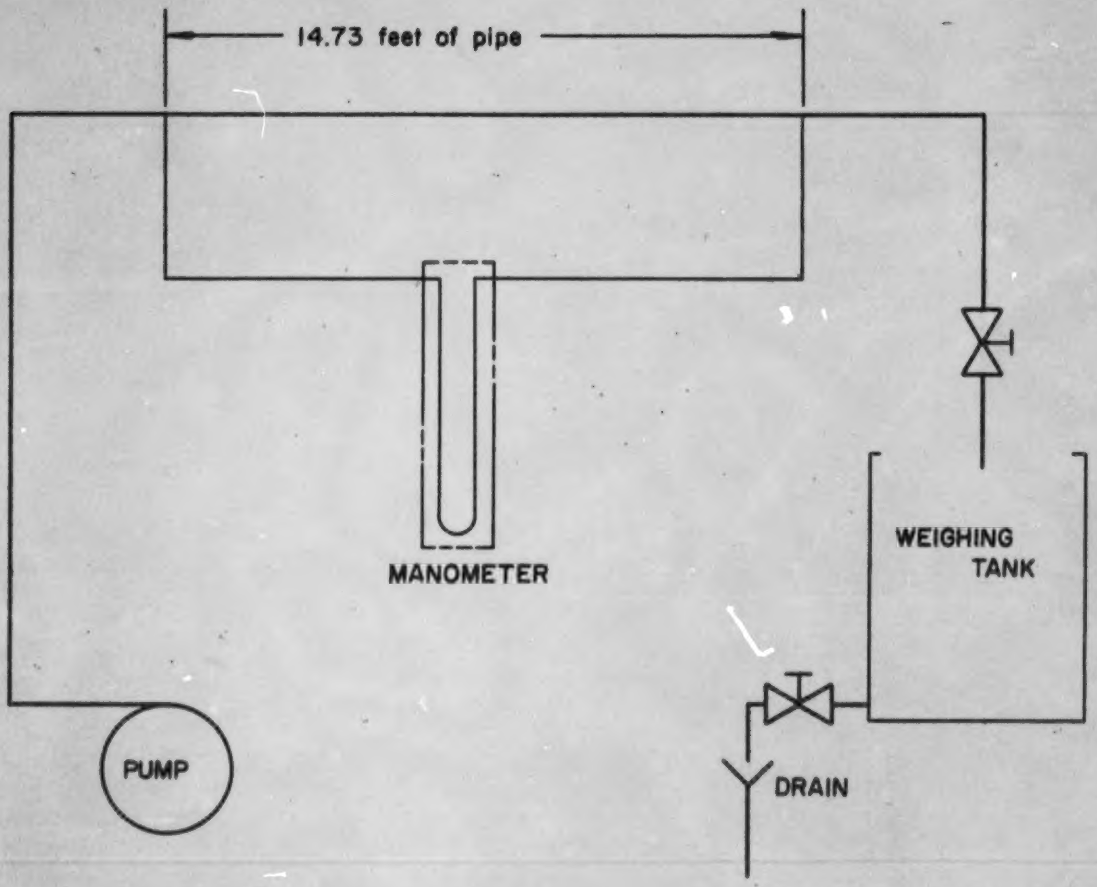

DYE INJECTION MECHANISM
SUPPLY VALVE
CONSTANT HEAD TANK
CONSTANT HEAD DRAIN
15.5"
DISCHARGE VALVE
TRANSPARENT PIPE
2.5"
WEIGHING TANK
DRAIN

APPROXIMATE TANK DIMENSIONS
12" wide x 18" deep x 24" long (inside)

REYNOLD'S NUMBER APPARATUS FOR PART 'A'

EXPERIMENT - 10B REYNOLDS NUMBER

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Pump Straight Pipe Manometer Weighing Tank Soft Tubing Stop Watch Pipe Taps Receiver Tank Platform scale	Refer to experiment 14.	Lost head in pipes and fittings. (Experiment performed on straight run between the two flanges.	No additional cost


14.73 feet of pipe
MANOMETER
WEIGHING TANK
PUMP
DRAIN

REYNOLD'S NUMBER APPARATUS FOR PART 'B'

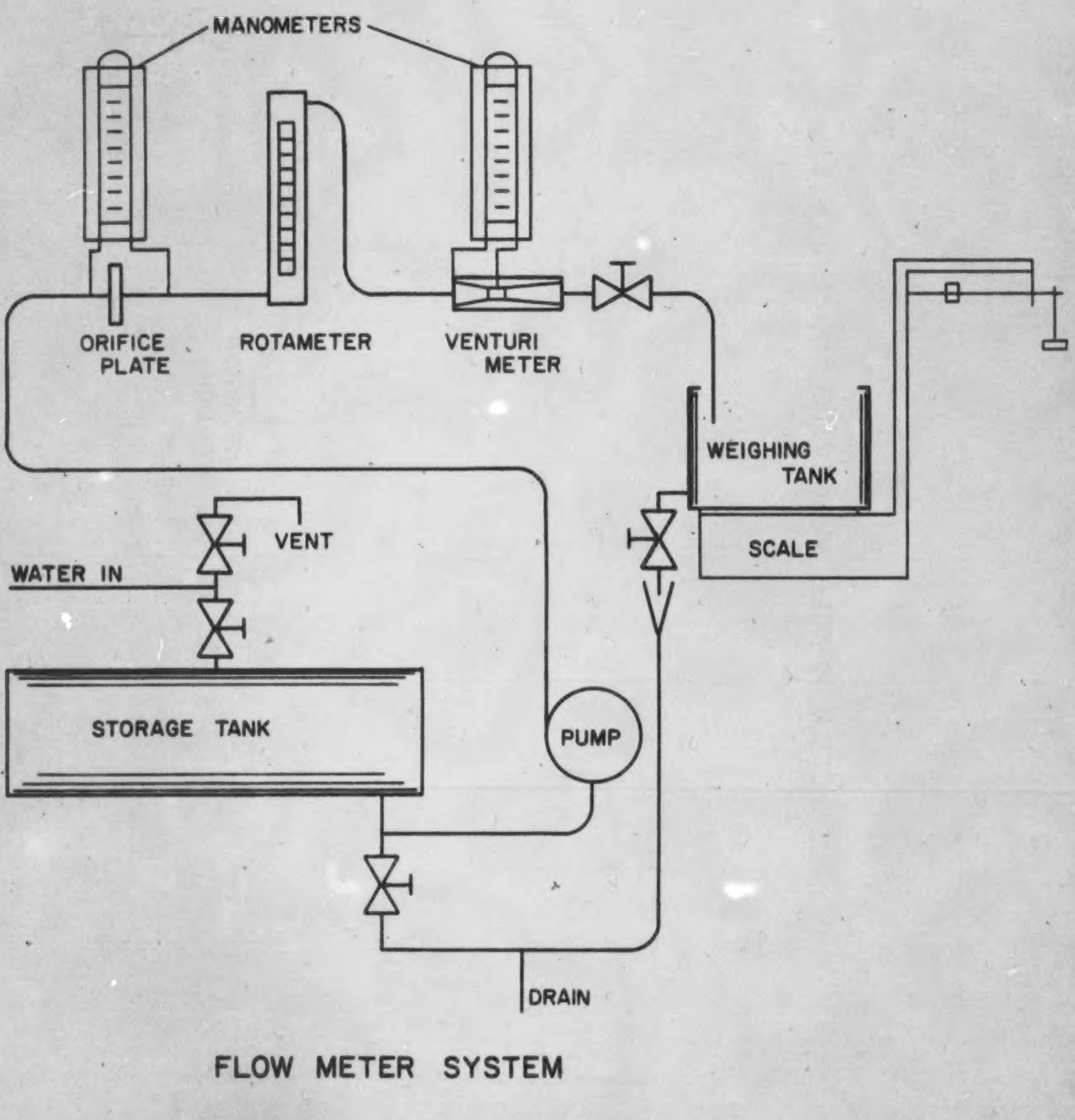
EXPERIMENT - 12 FLOW METERS

APPROXIMATE TOTAL COST $500

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Rotameter	Fischer & Porter Company Warminster, Penn. 18974 (215) 675-6000 Local Samuel B. Senior 10 Kearney Road Needham Heights, Mass. 02194 (617) 444-5750	Pg. 7 of Fischer's & Porter catalog # 10A1000 - 72, Model No. 3565-2-65-S liquid SP. GR. 1.0, visc. 1.0 CPS, flow units GPM, percent scale	$144.50
Bell & Gosset Booster Pump	Bell & Gossett Company Morton Grove, Illinois Local Ford & Ivester Assoc. 290 Second Ave. Waltham, Mass. (617) 890-0800	From Bell & Gosset catalog, AC motor, 1/12 HP, 1725 RPM, # PBB10-132-5-4, 100-1 DC	$125
Orifice Plate and Flanges	Can be produced in any machine shop.	Square edged orifice 0.688 in. Diameter	$10
U-Tube Manometer	The Meriam Instrument Co. 10920 Madison Avenue Cleveland, Ohio 44102 Local IWT Corp. 186 Crest Road P.O. Box 36 Needham, Mass. 02194	Pg. 4 of catalog #200 Model 10AA25TM with acessory 912A, range 20" (10-0-10) figure intervals 1", subdivision 0.1"	$25
Venturi with manometer taps	Best source for material	Can be produced in lab from transparent plexi-glass. Circular section 1 in. inlet ID by 0.625 in. throat ID	$30

EXPERIMENT - 12 FLOW METERS

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
30 gallon storage tank	Best source		$30
Weighing tank - 15 gallon capacity	Best source	Can be set up using the same tank of experiment No. 7B	$25
Scale - 200 lb. capacity	Best source		Approx. $100


MANOMETERS
ORIFICE PLATE
ROTAMETER
VENTURI METER
WEIGHING TANK
SCALE
VENT
WATER IN
STORAGE TANK
PUMP
DRAIN

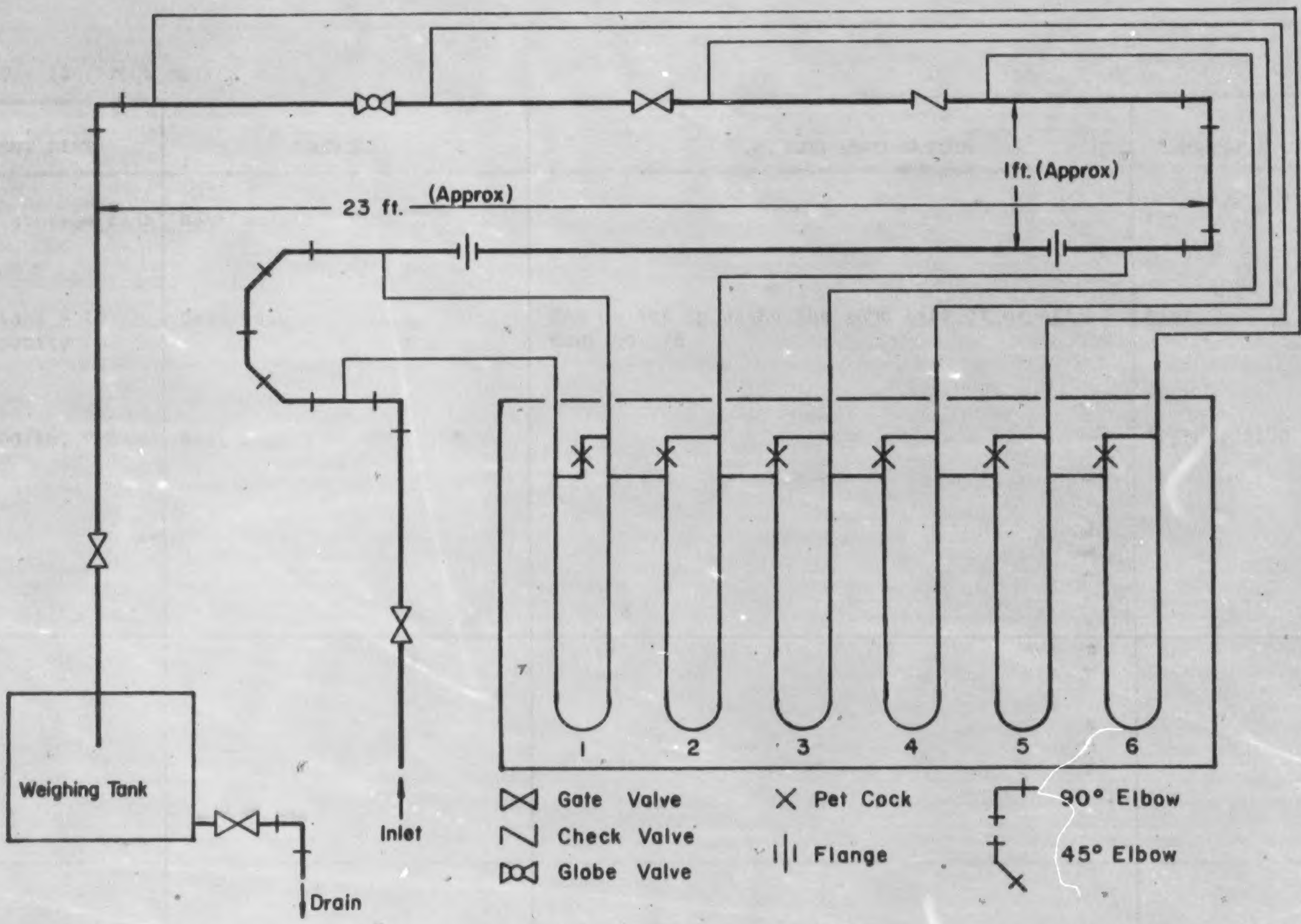
FLOW METER SYSTEM

EXPERIMENT - 13 LOST HEAD IN PIPES AND FITTINGS APPROXIMATE TOTAL COST $600

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Pump & Motor	Worthington Pumps Local Worthington Corp. 2000 Commonwealth Avenue Newton, Mass. 02159 (617) 969-0973	Worthington catalog - cast iron threaded connection pump and motor, 45GPM, 60 ft. total head, 1 1/2 HP, 3600 RPM drip proof, 1 1/2 x 1 x 4, D520 pump, 3 phase 230/460 motor	$180
Manometers - 6	The Meriam Instrument Co. 10920 Madison Avenue Cleveland, Ohio 44102 Local IWT Corp. 186 Crest Road, P.O. Box 36 Needham, Mass. 02194 (617) 444-3632	Pg. 4 catalog #200, Model 10AA 25 WM (wall mounting type) range 20" (10-0-10), Figure Intervals 1"; subdivision 0.1"	$24/manometer $10 mercury/ manometer
Gage	Best Source	1 - #500S U. S. Pressure gage 0 to 100 pounds 3 1/2" diameter dial	$4
Platform scale, weighing & receiver tanks	Can share system available in experiment No. 14.		

NECESSARY VALVES AND FITTINGS $190-210

1. 60 ft - 1 inch I.D. type L copper tubing
2. 1 - 1 inch copper globe valve
3. 3 - 1 inch copper gate valves
4. 1 - 1 inch copper check valve
5. 4 - 1 inch copper to copper flanged unions
6. 7 - 90° long radius wrot copper ells
7. 4 - 45° wrot copper ells
8. 2 - 50 ft. rolls type K, 1/4 inch O.D. soft copper tubing
9. 7 - 1/4"C x 1/4" MPT brass compression connectors
10. 17 - 1/4"C compression tees
11. 7 - 1/4"C compression ells
12. 6 - 1/4"C compression union brass shut-offs
13. 12 - 1/4"C x 1/4" MPT compression ells


23 ft. (Approx)
1ft. (Approx)
1
2
3
4
5
6
Weighing Tank
Inlet
Drain
Gate Valve
Check Valve
Globe Valve
Pet Cock
Flange
90° Elbow
45° Elbow

Lost Head Piping System

EXPERIMENT - 14 CENTRIFUGAL PUMP

Approximate Total Cost $1,350

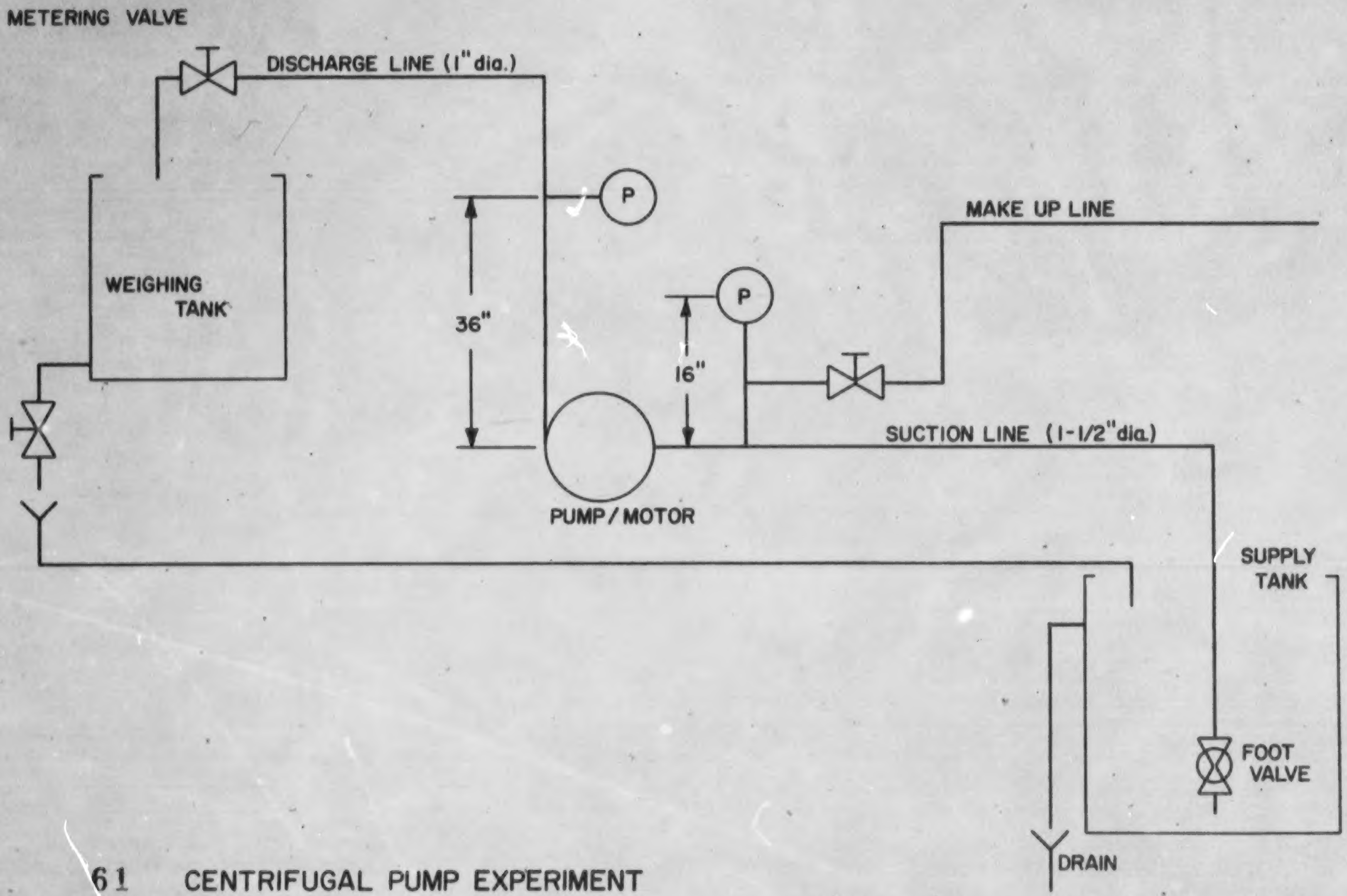
EQUIPMENT	SOURCE	CATALOG INFORMATION	PRICE
Pump	Worthington Pumps Local Worthington Corp. 2000 Commonwealth Avenue Newton, MA 02159 (617) 969-0973	Experiment conducted on 1-CN-52, single stage, single end suction vertically split case, enclosed impeller 1" discharge 1 1/2" suction Worthington pump. (A pump equivalent to this would be Worthington's D511, 1 1/2 x 1 x 5.)	$215
Drive	U. S. Electric Motors Inc. 1-800-243-2820	U. S. 3HP frame 14-213 Vari-Drive 440 volts, 3 phase 60 cycle, speed variation 1970 and 3940 RPM.†	$700
Voltmeter	Simpson Electric Co. 5200 West Kinzie Street Chicago, Illinois 60644 (312) 379-1121 Local Paul R. Sturgeon Co. 1330 Boylston Street (617) 734-7710	Pg. 9 of Simpson catalogue. Bulletin No. 2079, 0-300 volt AC, Model #59, catalogue No. 8810, 4 1/2" case.	$19.65
Ammeter	Simpson Electric Co.	Pg. 9 of Simpson catalogue. Bulletin No. 2079, 0-15 amps AC, Model #59, catalogue No. 1350, 4 1/2" case.	$19.20
Platform Scale	Best Source	200-300 pound capacity	$100
Weighing Tank	Best Source	200-300 pound capacity	$40
Receiver Tank	Best Source	Approximate size 4' x 4' x 4', 4000 lb. capacity	$100
Stop Watch	Best Source		$12
Fittings and Accessories*	Best Source		$90-100

†Type VATF, frame 15-182T, 3HP, 230/460 volts, 1970 and 3940 speed is equivalent to motor used.

*See following page

FITTINGS AND ACCESSORIES NEEDED FOR CONSTRUCTION

1. 10 ft - 1 1/4 inch I.D. type L copper tubing
2. 20 ft - 1 inch I.D. type L copper tubing
3. 2 - 1 1/4 long radius wrot copper ells
4. 4 - 1 inch long radius wrot copper ells
5. 1 - 1 inch bronze lever gate valve
6. 1 vacuum gage range 0 - 30 in. Hg.
7. 1 pressure gage range 0 - 60 lbs.
8. 1 - 1 1/4 bronze foot valve


METERING VALVE
DISCHARGE LINE (1" dia.)
P
MAKE UP LINE
WEIGHING TANK
36"
P
16"
SUCTION LINE (1-1/2" dia.)
PUMP / MOTOR
SUPPLY TANK
FOOT VALVE
DRAIN

61 CENTRIFUGAL PUMP EXPERIMENT

EXPERIMENT - 17 ENGINE TESTING APPROXIMATE TOTAL COST $1700

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Megatech Mark III Transparent Engine & DG1 Electric Dynamometer/Generator	Megatech Corporation 29 Cook Street Billerica, Mass. 01866 (617) 273-1900	Pg. 6 - 7 of 1972 Megatech catalog Engine Specifications - 1/2 HP, 400-4000 RPM, 3/1 & 4/1 compression ratios, air cooled, uses various fuels. DG-1 specifications - up to 1.3 HP at 3500 RPM, 0-24 in - lb torque, air cooled, continuous operation.	$499/Mark III Engine $899/DG 1
*Air Compressor minimum capacity of 2 CFM @ 20 psi *Not necessary if lab equiped with an air compressor	Megatech Corporation 29 Cook Street Billerica, Mass. 01866 (617) 273-1900	pg. 88 of 1972 Megatech catalog Speedaire spray unit Model No. 2Z371, 1/2 HP 2.9 CFM @ 40 psi, max psi 50 115V, 60 cycle motor.	$86.00
Air Regulator & Accessories	Independent Pipe and Supply 200 New England Avenue Dorchester, Mass. (617) 825-3500	1-1/2 in watts # 118-4 0/125 pressure regulator 1-watts # 602-4 air filter 1-MTG bracket # 18A 57 1-2 1/2" # 800 0/160 lb, pressure gage	$30.25
Battery Charger	Sears Roebuck Co. 201 Brookline Avenue Boston, Mass.	12 volt 10 AMP battery charger # 28K 7198C	$34.45
Timing Light	Sears Roebuck Co. 201 Brookline Avenue Boston, Mass.	Sears catalog catalog # 28 B2159 AC powered timing light	$16.46

EXPERIMENT - 17 ENGINE TESTING

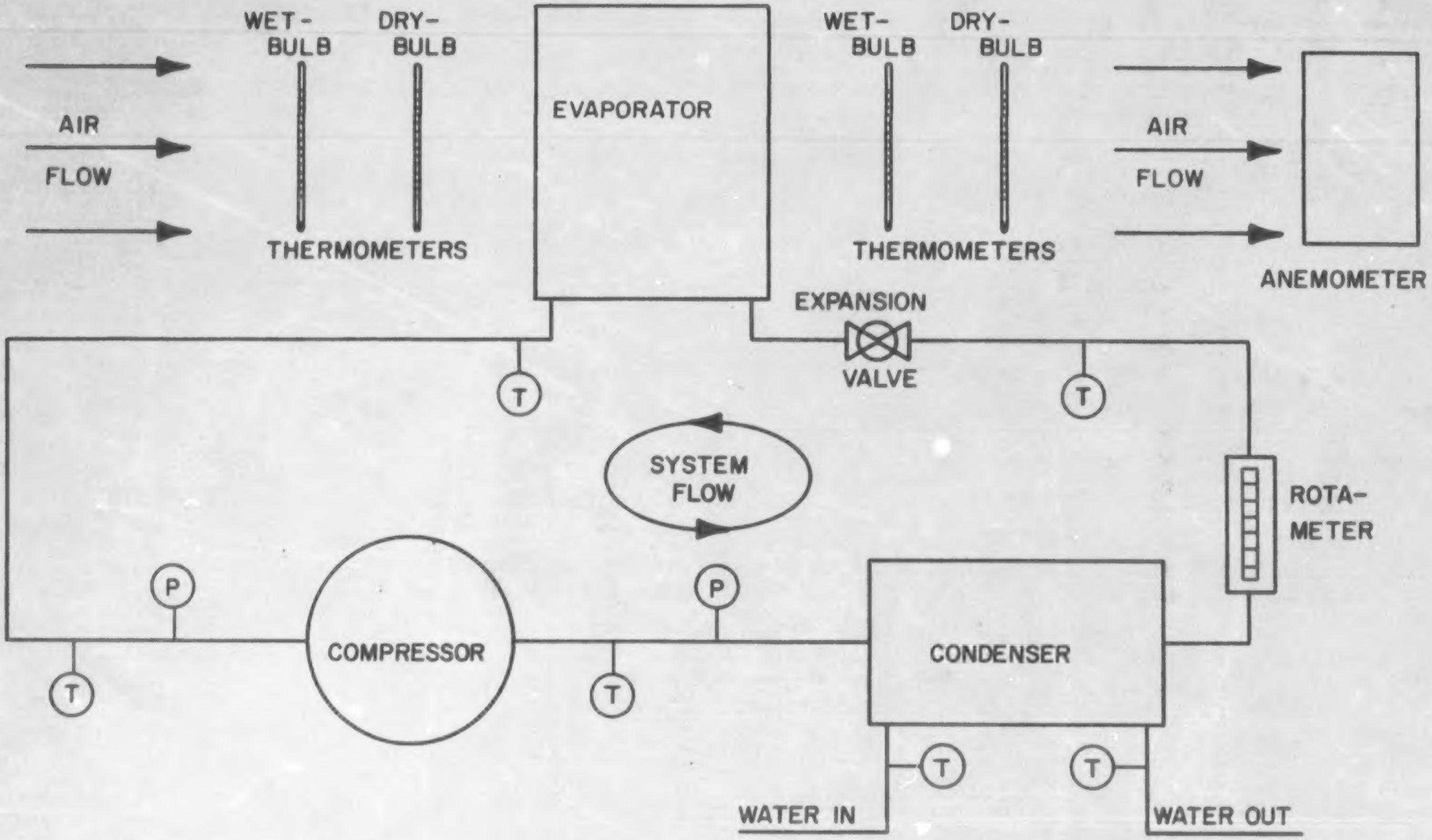
EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Weighing Scale	SciChemCo 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 35 SciChemCo catalog # 71 # 3-422 Ohaus triple beam balance 2610 gram capacity, 6 in diameter stainless steel plate	$32.50
Dwyer Air Meter	Dwyer Instruments Inc. Highway 212 at 12 P.O. Box 373 Michigan City, IND 46360 (219) 872-9141	Pg. 6 of Bulletin F-41 of 1972 Dwyer catalog model RMC-103, 10 in. scale. No. metering valve, 1/2 in. NPT connections, 20-200 SCFH air	$41.90
Brooks Rotameter	Brooks Instrument Division 407 W. Vine Street Hatfield, Penn. 19440 855-5174 Local King Gage Engineering Corporation 83 Oak Street Natick, Mass. 02170 (617) 237-5817	Pg. 3 of bulletin DS-1335-1357 tube number R-2 15-D, 150 MM scale, stainless steel float, max flow rate 20.8 cc/min of water	$29

EXPERIMENT - 18 VAPOR COMPRESSION SYSTEMS APPROXIMATE TOTAL COST $1250

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
1.5 ton Dunham - Bush open type water cooled condensing unit	A.E. Borden Inc. 184 Everett Street Allston, Mass. 02134 (617) 787-0900	Page 34 of catalog I 72 cat. no. WC150 FH, R-12 refrigerant, 1.5 HP, 336.7 CFH displacement, 565 RPM, 2 cylinder, 1 phase 115/230	$670
Blower Coil	Best Source	Select coil to match condensing unit	Approximately $300
Expansion valve for 1.5 tons R-12 externally equilized	Best Source		$20.00
Bacharach sling psychrometer	A. E. Borden	Page 14 of catalog I 72 cat. no. 12-7011 mercury type	$16.25
Robinair three lead - dual range temperature tester	A. E. Borden	Page 91 of catalog I 72 cat. no. 12860, range -50°F to +50°F and +50°F to +150°F, accuracy ± 2°F between -40°F to +40°F.	$70
* Davis Anemometer * Used also in velocity measurement	Davis Instrument Manuf. Co. 513 East 36th Street Baltimore, Maryland 21218 Local Charles T. Morgan Co., Inc. 500 Maple Street Danvers, Mass.	Biram type A/2 - 4" range 100 - 5000 FPM	No additional cost

EXPERIMENT - 18 VAPOR COMPRESSION SYSTEMS

EQUIPMENT LIST	SOURCE	CATALOG INFORMATION	PRICE
Robinair Manifold	A. E. Borden	Page 93 of catalog I 72 cat. no. CMN - 4-15, complete with case. Used for testing, evacuating, recharging or setting controls. 0-500 psi range, pressure gage, compound gage 30 in. mercury vacuum to 120 psi.	$26.55
Ranco Dual Commercial Pressure Control	A. E. Borden	Page 85 of catalog I 72 cat. no. 012-1506 range 100-250 psi high pressure 12 in. vac to 50 psi low pressure	$22.20
Ratosight Type Rotameter	Fischer & Porter Company Warminster, Pennsylvania 18974 (215) 675-6000 Local Samuel B. Senior 10 Kearney Road Needham Heights, Mass. 02194 (617) 444-5750	Page 8 of Fischer Porter catalog 10A 1000 - 72 Model 10A 2235A catalog no. 2235573 GPM 0.2 to 2.0 direct reading, ± 5% full scale accuracy	$46.75
Hershey Disc Type flowmeter	Hershey Products Inc. 250 Elm Road Dedham, Mass. (617) 326-9400	3/4" with connections, Model MHF	$61.81


WET-BULB
DRY-BULB
AIR FLOW
THERMOMETERS
EVAPORATOR
WET-BULB
DRY-BULB
THERMOMETERS
AIR FLOW
ANEMOMETER
EXPANSION VALVE
T
T
SYSTEM FLOW
ROTA-METER
P
P
COMPRESSOR
CONDENSER
T
T
T
T
WATER IN
WATER OUT

VAPOR COMPRESSION TEST SYSTEM

EXPERIMENT - 19 HEAT EXCHANGERS Approximate Total Cost $400

EQUIPMENT	SOURCE	CATALOG INFORMATION	PRICE
4-thermometers	Sci Chem Co 45 Williams Avenue Everett, MA 02149 (617) 389-7000	Pg. 914 of catalogue #71. Catalogue No. 79-757-02, 0-230°F, 2° subdivision, 76mm immersion	$3.60 each
Weighing Tank	Best Source	100-200 lb. capacity	$30
Platform Scale	Best Source	100-200 lb. capacity	Approx. $100
Stopwatch	Best Source		$12
Roll fiberglass insulation Blanket 400 ft^2 x 1" thick	Best Source Local Eckel Industries Inc. 155 Fawcett Street Cambridge, MA		$45.00
Fittings and Accessions *	Best Source		$170-$200

* See following page

FITTINGS AND ACCESSORIES NEEDED FOR CONSTRUCTION OF HEAT EXCHANGER

6' - 3/8" O.D. type L.C. tubing

8' - 1/2" O.D. type L.C. tubing

4 - 1/4" comp x 1/4 M.P.T. adapters

4 - 1/2" C. ells

3 - 3/8" bronze check valves

6 - 1/2" M.P.T. x 1" male hose adaptor

2 - 3/8" C. x 1/2" C. coupling

4 - 1/2" C. x 1/2" M.P.T. adapters

6 - 1/2" C. x 3/8" M.P.T.

2 - 5/8" C. globe valves

10' - 1 1/8" O.D. type L.C. tubing

4 - 1 1/8" x 1 1/8" x 5/8"tees

2 - 1 1/8" x 1 1/8" copper couplings

20' - 5/8" O.D. type L. C. tubing

6 - 5/8" C. ells

2 - 5/8" C. tees

10' - 1 1/2" I.D. copper tubing

2 - 1 1/2" C. ells

1 - 1 1/2" C. tee

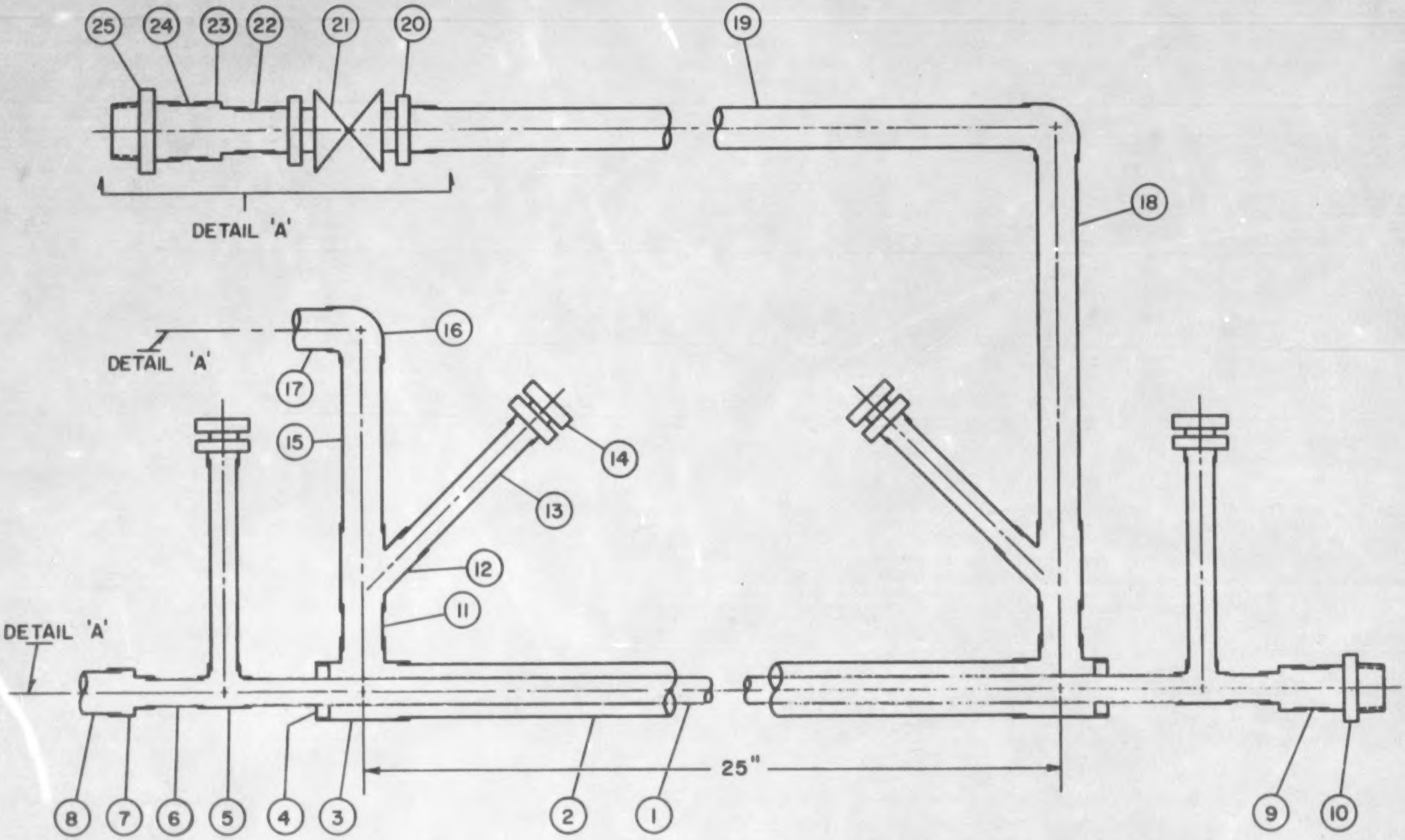
2 - 1 1/2" C. x 4" soil fittings

8 - brass garden hose couplings

25' - Boston rubber garden hose

6 - cast brass hose nipples

8 - aeroseal hose clamps


25
24
23
22
21
20
19
DETAIL 'A'
18
16
DETAIL 'A'
17
15
14
13
12
11
DETAIL 'A'
25"
8
7
6
5
4
3
2
1
9
10

HEAT EXCHANGER ASSEMBLY

HEAT EXCHANGER ASSEMBLY

PARTS LIST

(ALL TUBING TYPE L COPPER)

Part No.	Quantity	Description
1	1	1/4" pipe
2	1	1/2" pipe
3	2	1/2 x 1/2 x 3/8" tee
4	2	1/2 x 1/4" short reducer (drilled thru)
5	2	1/4 x 1/4 1 1/4" tee
6	2	1/4" pipe
7	1	3/8 x 1/4" long reducer
8	1	3/8" pipe
9	1	1/2" pipe
10	1	1/2 x 1/2" M adapter
11	2	3/8" pipe
12	2	3/8 x 3/8 x 1/4" Y
13	4	1/4" pipe
14	4	1/4" tube x 1/8" MPT COMPR. M.C. (drilled to fit)
15	1	3/8" pipe
16	2	3/8 x 3/8" 90° - ell
17	1	3/8" pipe
18	1	3/8" pipe
19	1	3/8" pipe
20	6	3/8 x 3/8" MPT
21	3	3/8" needle valve
22	3	3/8" pipe
23	3	1/2 x 3/8" long reducer
24	3	1/2" pipe
25	3	1/2 x 1/2" M adapter

EXPERIMENT - 20 METALS AS HEAT CONDUCTORS Approximate Total Cost $280

EQUIPMENT	SOURCE	CATALOG INFORMATION	PRICE
Portable potentiometer	Leeds & Northrup Co. North Wales, Penn. 19454 Local Leeds & Northrup Co. 875 Providence Highway Dedham, Mass. 02026 (617) 326-8816	Pg. J-12 of Leeds & Northrup catalog #H0.0001-A573, Model No. 8696-2, double range, 0-22 and 20 - 64 mv.	$322 *
Copper - constantan thermocouple wire	Leeds & Northrup Co.	30 feet length - refer to experiment No.- 4	$0.14/foot * * Not included in approximate total cost.
Station selector switch	Leeds & Northrup Co.	Pg. B-49 of Leeds & Northrup catalog #H0.0001 - A573, Model No. 8248-10, 10 point capability	$80
Immersion heater	Sci Chem Co 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 498 of catalog #71, catalog No. 42-650-06, 1000 watts capacity, flexible electric type	$17.50
4 - thermometers	Sci Chem Co 45 Williams Street Everett, Mass. 02149 (617) 389-7000	Pg. 916 of catalog #71, catalog No. 80-100-09, ASTM No. 9F, Pensky-Martens low, 20-230°F, 1° subdivisions	$5.50 each
Sealed copper heat pipe	Edmund Scientific Co. 402 Edscorp Building Barrington, N.J. 08007 (609) 547-3488	Pg. 12 of Edmund catalog #731, No. 60,861, operates in ranges of 80-200°C, 10 inches long	$25.50
Variable transformer type 3PN116B	Fisher Scientific Co. 711 Forbes Avenue Pittsburgh, Penn. 15219 Local 461 Riverside Avenue Medford, Mass. 02155 (617) 391-6110	Pg. 387, Fisher catalog, catalog No. 9-521-5 powerstat, 10 amps.	$34

EXPERIMENT - 20 METALS AS HEAT CONDUCTORS (cont.) Approximate Total Cost

EQUIPMENT	SOURCE	CATALOG INFORMATION	PRICE
15 ft^2 styrofoam insulation 3/4" thick	Best Source Local Eckel Industries Inc. 155 Fawcett Street Cambridge, Mass.		$45
Sheet 21 gage copper 2' x 4' 3' copper rod - 3/8"D. 3' aluminum rod-3/8"D.	Best Source Local Admiral Brass-Copper Co. Inc. 444 Somerville Avenue Somerville, Mass. (617) 666-5800		$50

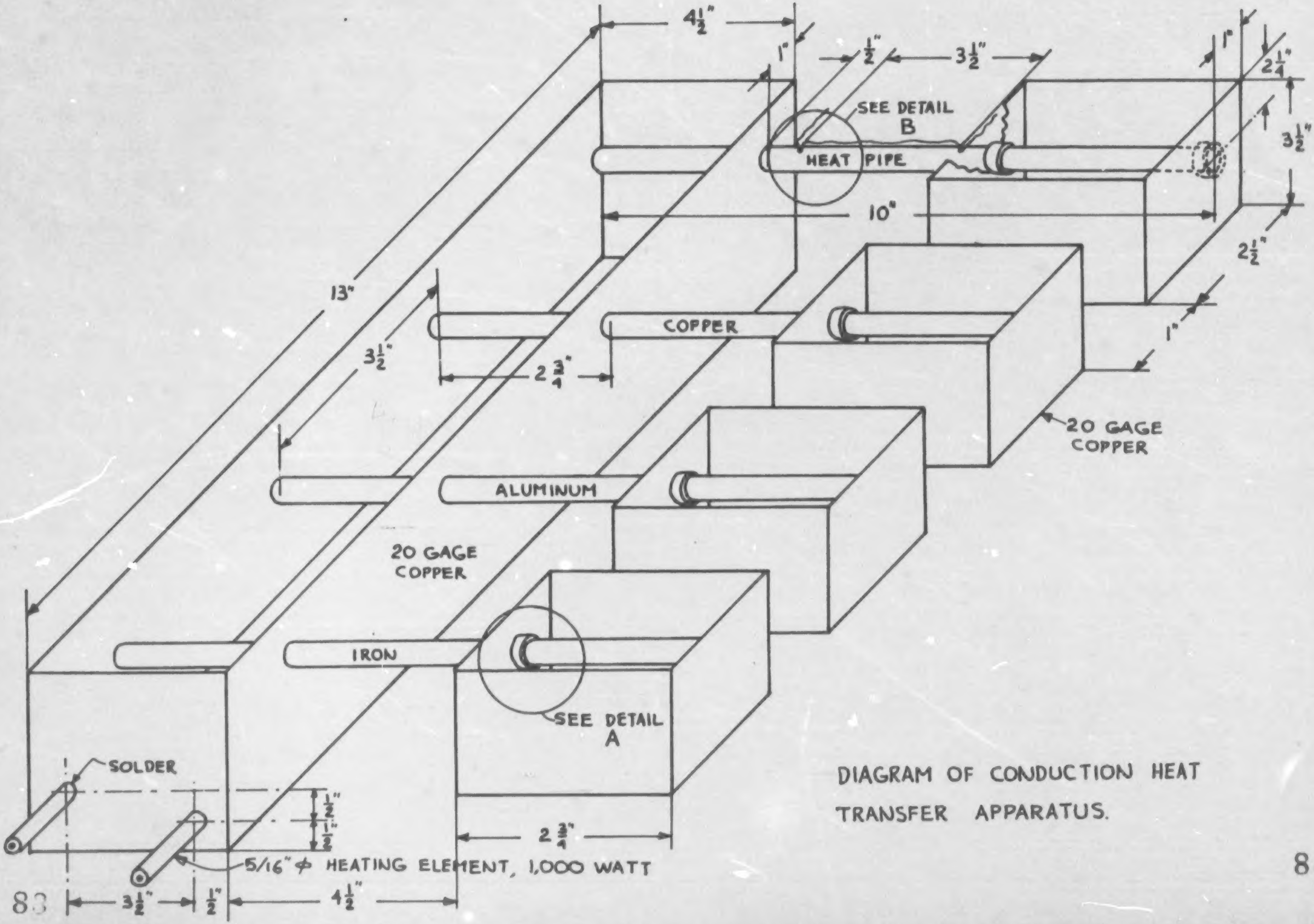
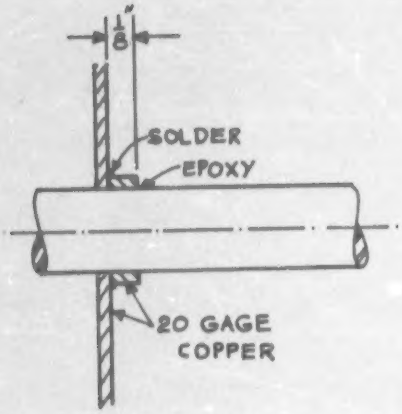
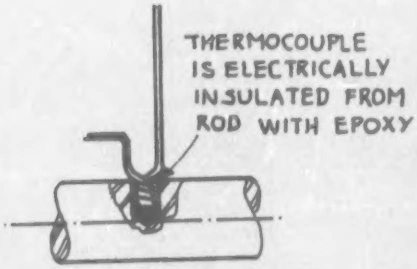

4½"
1"
½"
3½"
1"
2¼"
SEE DETAIL
B
HEAT PIPE
3½"
10"
2½"
13"
3½"
COPPER
2¾"
1"
20 GAGE
COPPER
ALUMINUM
20 GAGE
COPPER
IRON
SEE DETAIL
A
SOLDER
½"
½"
5/16" ϕ HEATING ELEMENT, 1,000 WATT
2¾"
3½"
½"
4½"

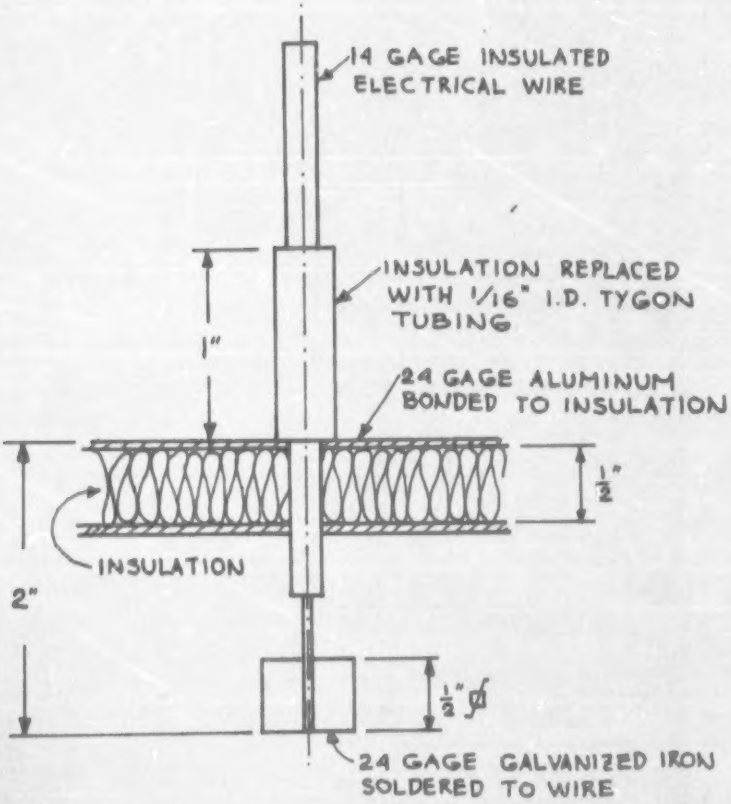
DIAGRAM OF CONDUCTION HEAT TRANSFER APPARATUS.


1/8"
SOLDER
EPOXY
20 GAGE COPPER

DETAIL - A


THERMOCOUPLE IS ELECTRICALLY INSULATED FROM ROD WITH EPOXY

DETAIL - B


14 GAGE INSULATED ELECTRICAL WIRE
INSULATION REPLACED WITH 1/16" I.D. TYGON TUBING
1"
24 GAGE ALUMINUM BONDED TO INSULATION
1/2"
INSULATION
2"
1/2" Ø
24 GAGE GALVANIZED IRON SOLDERED TO WIRE

DETAIL OF COLD WATER STIRRING DEVICE THROUGH LID (ONE IN EACH CUP)

EXPERIMENT NO. 1

GRAPHING TECHNIQUE

SAMPLE CALCULATIONS

1. EXPERIMENTAL THERMOCOUPLE No. 409 A

a) VOLTAGE OUTPUT (E)

$$E = 0.020T + 0.80 \qquad T = {}^\circ F$$

$$= \left(0.020 \frac{mv}{{}^\circ F}\right)(100\ {}^\circ F) + 0.80\ mv$$

$$= 2.80\ mv$$

2. IDEAL GAS $PV^n = C$

a) DETERMINATION OF SLOPE (m) FROM LOG PLOT

$$m = \frac{\Delta Y}{\Delta X} = \frac{Y_2 - Y_1}{X_2 - X_1}$$

$$= \frac{-4.5}{2.25}$$

$$= -2$$

b) PROOF: $n = -m$

$$PV^n = C$$

$$P_1 V_1^n = P_2 V_2^n$$

$$\left(\frac{V_1}{V_2}\right)^n = \frac{P_2}{P_1}$$

$$(n)\ln\frac{V_1}{V_2} = \ln\frac{P_2}{P_1}$$

$$n = \frac{\ln P_2 - \ln P_1}{\ln V_1 - \ln V_2}$$

$$= \frac{\ln 200 - \ln 800}{\ln 20 - \ln 40}$$

$$= \frac{5.30 - 6.68}{3.00 - 3.69}$$

$$= \frac{-1.38}{-0.69}$$

$$\left.\begin{aligned} n &= 2 \\ m &= -2 \\ -m &= 2 \end{aligned}\right\} \therefore\ n = -m$$

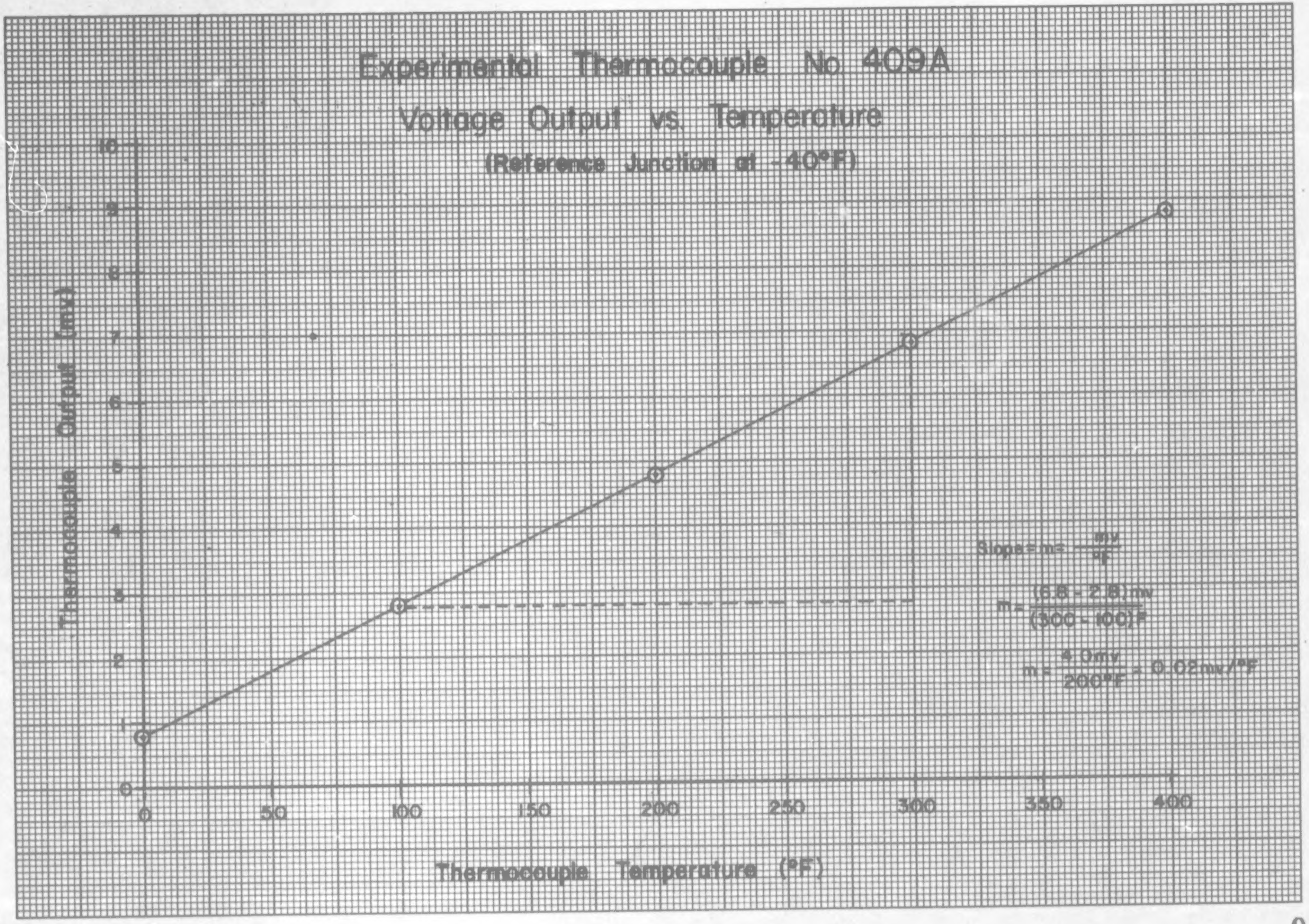
c) DETERMINATION OF CONSTANT (C)

$PV^n = C$

$P = 800$ lb/in^2 $V = 20$ in^3 $n = 2$

$C = (800\ \text{lb/in}^2)(20\ \text{in}^3)^2$

$C = 32 \times 10^4$ lb-in^4



Experimental Thermocouple No. 409A

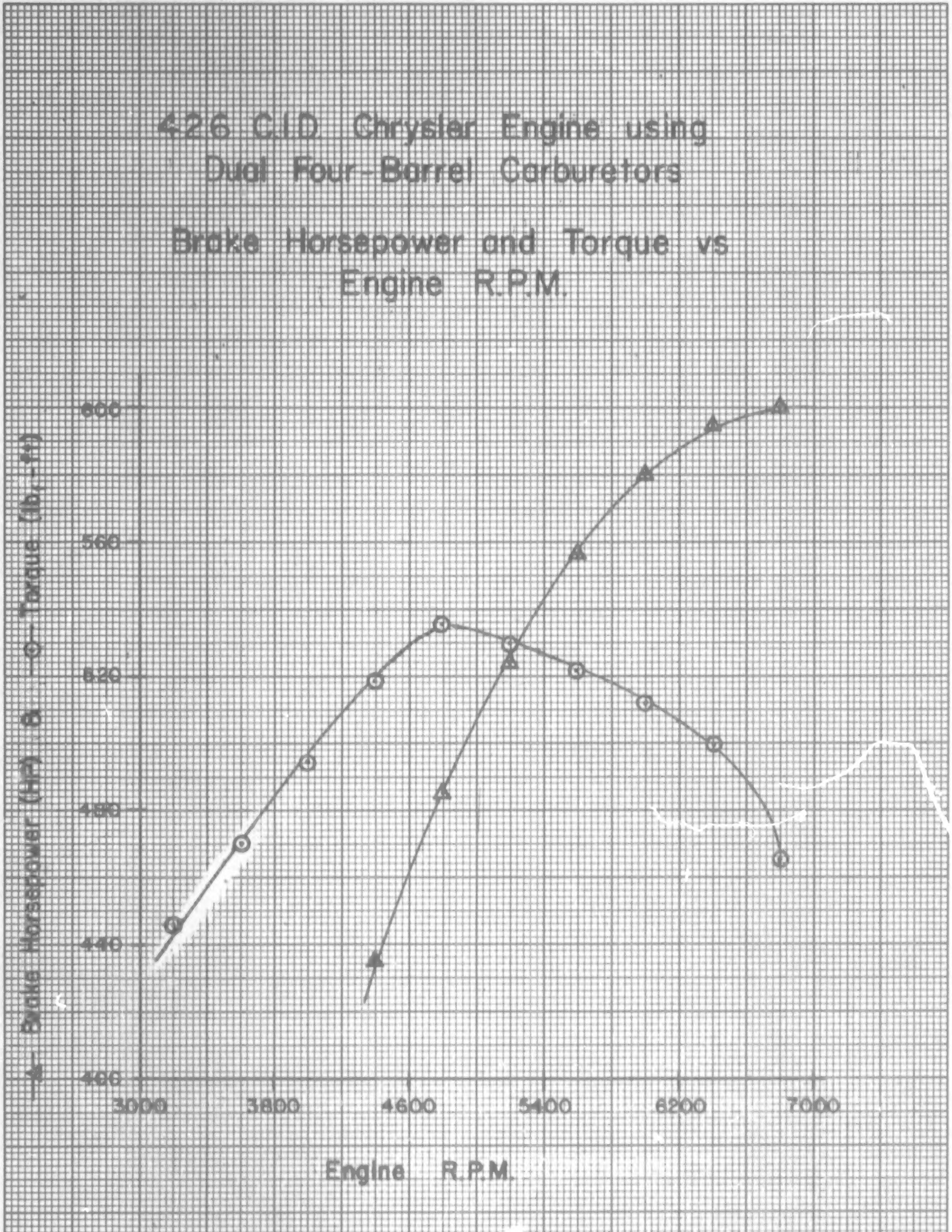
Voltage Output vs. Temperature

(Reference Junction at -40°F)

$$\text{Slope} = m = \frac{\text{mv}}{°\text{F}}$$

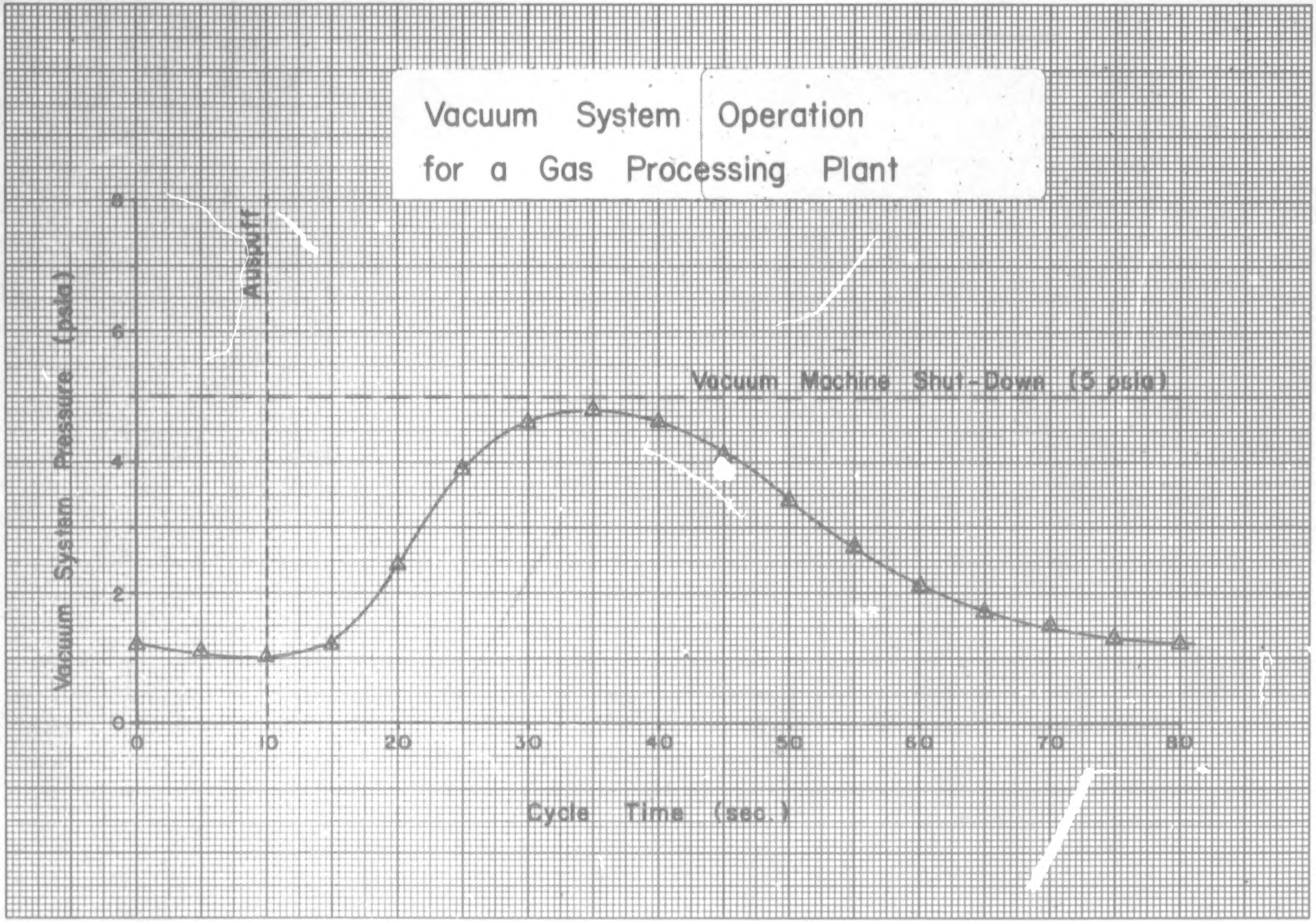
$$m = \frac{(6.8 - 2.8)\,\text{mv}}{(300 - 100)\,\text{F}}$$

$$m = \frac{4.0\,\text{mv}}{200\,°\text{F}} = 0.02\,\text{mv}/°\text{F}$$

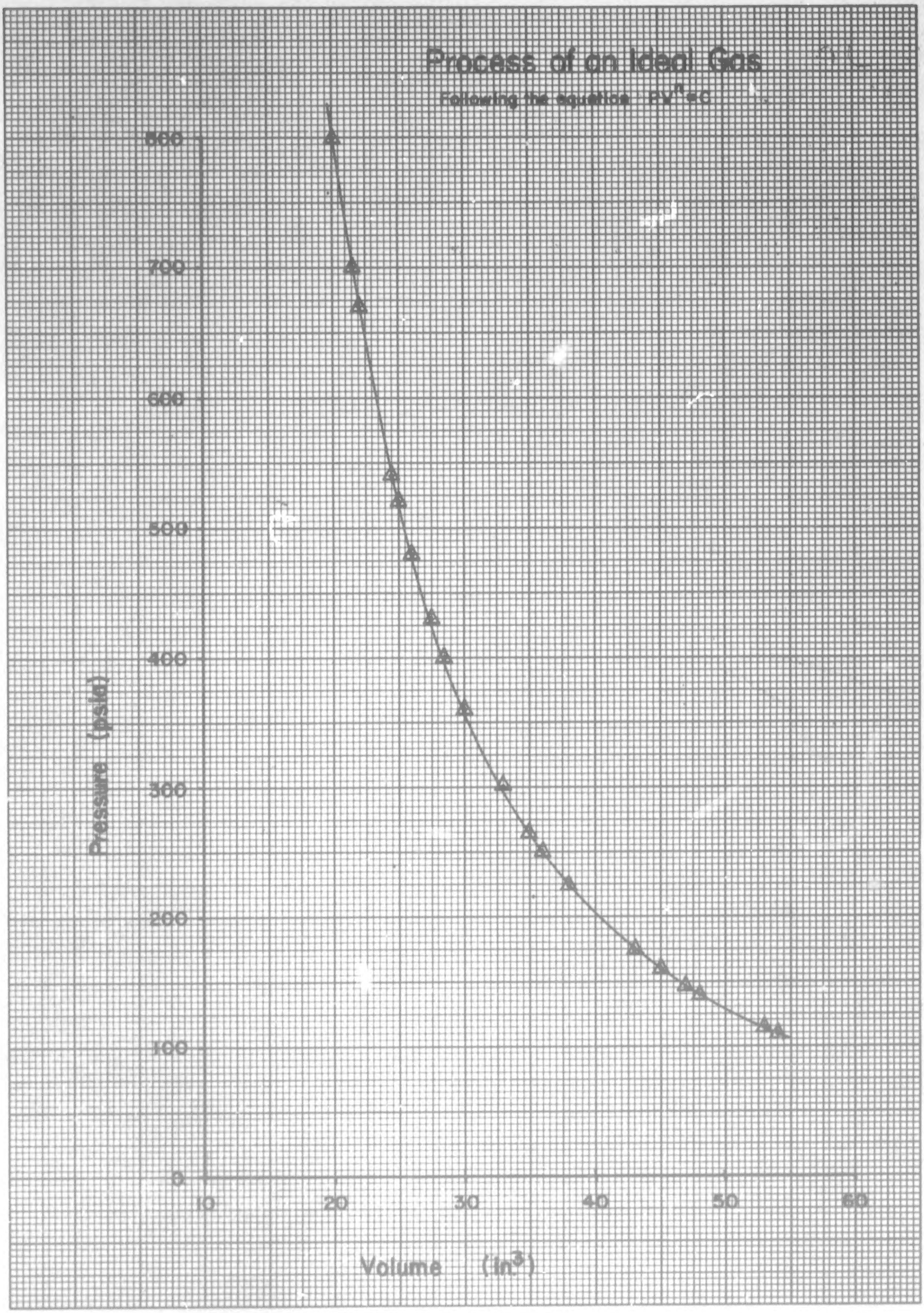


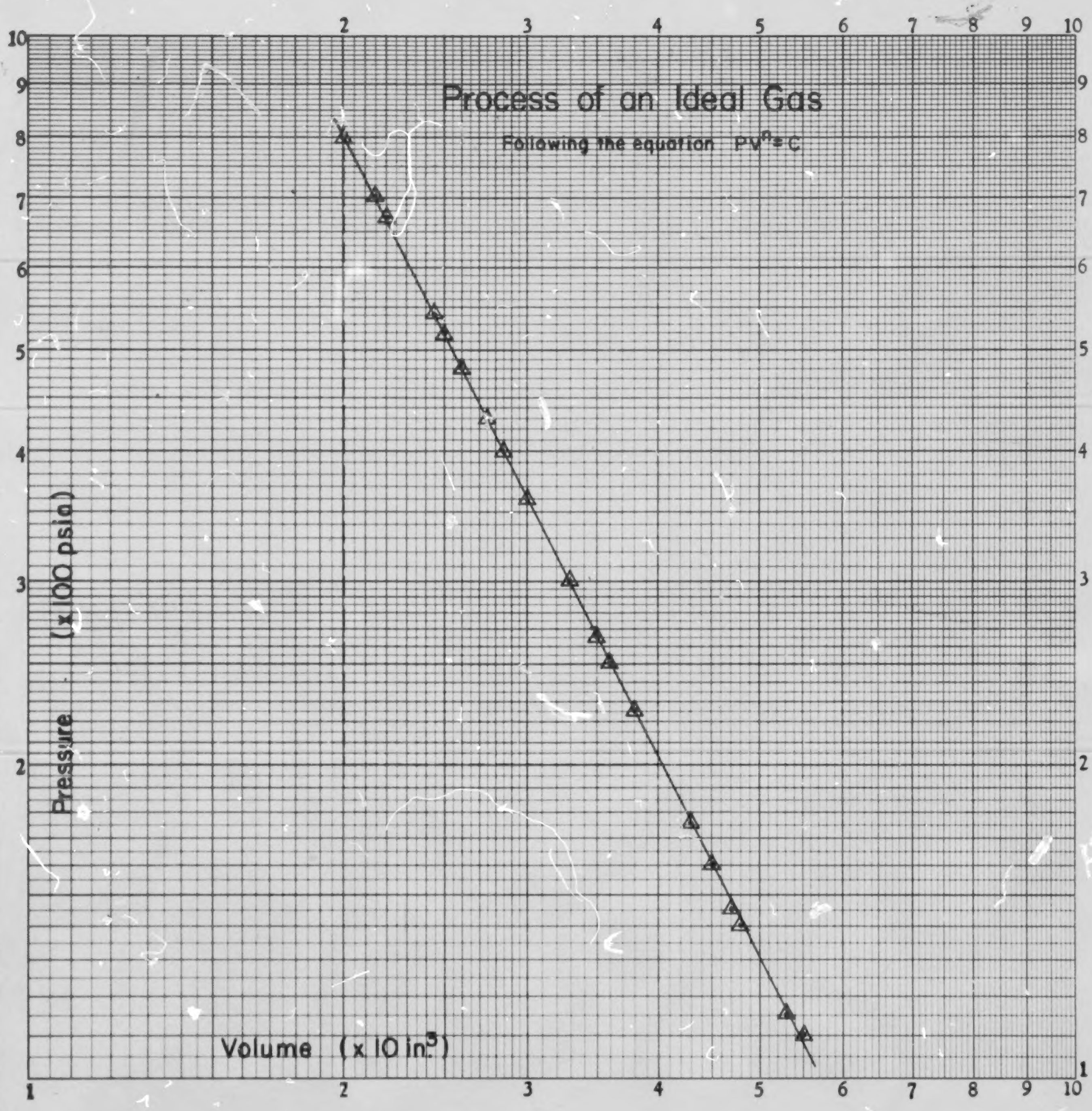
426 C.I.D. Chrysler Engine using Dual Four-Barrel Carburetors

Brake Horsepower and Torque vs Engine R.P.M.



Vacuum System Operation for a Gas Processing Plant


Process of an Ideal Gas
Following the equation $PV^n = C$
800
700
600
500
400
300
200
100
0
Pressure (psia)
10
20
30
40
50
60
Volume (in³)


Process of an Ideal Gas
Following the equation PV^n= C
Pressure (x 100 psia)
Volume (x 10 in.^{3})
1
2
3
4
5
6
7
8
9
10

EXPERIMENT NO. 2

PRESSURE MEASUREMENT

Data Sheet

Well-Type inches Hg	No 1. U-tube inches Hg	No 2. U-tube inches Hg	Test Gage psi	Inclined inches Hg
1.0	0.00	-0.25	0.00	1.50
2.0	0.95	0.65	0.45	2.75
3.0	2.00	1.65	0.95	4.00
4.0	3.00	2.65	1.50	5.40
5.0	4.00	3.70	2.00	6.85
6.0	5.05	4.70	2.50	8.30
7.0	6.05	5.70	3.00	9.65
8.0	7.05	6.70	3.53	11.10
9.0	8.05	7.80	4.00	12.50
10.0	9.05	8.70	4.50	14.10
11.0	10.05	9.70	5.05	15.40

Specific Gravity of red fluid 0.827 **Height of red fluid** 1.2 in.
Specific Gravity of blue fluid 1.75 **Height of blue fluid** 3.0 in.
Specific Gravity of mercury 13.6
Inclined manometer angle 45°
Diameter ratio well/tube 10/1

SAMPLE CALCULATIONS

1. WELL MANOMETER

$$h_2 = \text{FINAL LEVEL} - \text{INITIAL LEVEL}$$

$$= 5\text{ in.} - 1\text{ in.}$$

$$= 4\text{ in.}$$

$$P = K\gamma h_2 \left[1 + \left(\frac{d_2}{d_1}\right)^2\right]$$

$$= \frac{1\text{ ft}^3}{1728\text{ in.}^3}(62.4\ \text{lbf/ft}^3)(13.6)(4\text{ in.})\left[1+\left(\frac{1}{10}\right)^2\right]$$

$$= 1.98\ \text{lbf/in.}^2$$

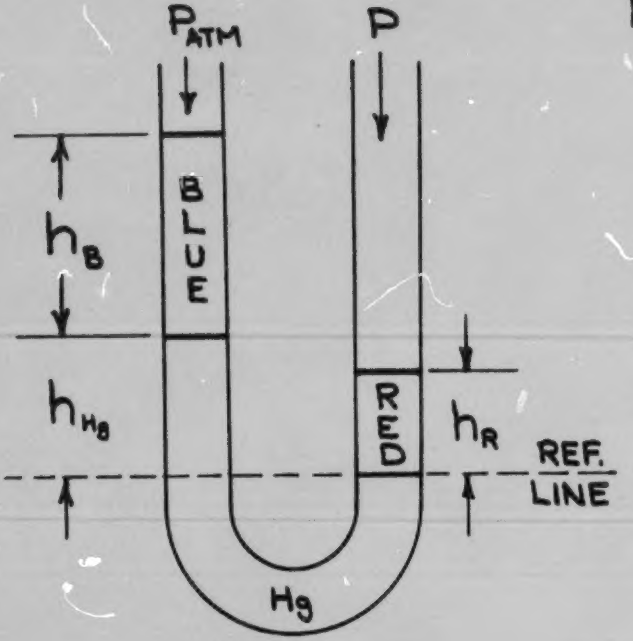
2. U-TUBE MANOMETER No. 1

$$P = (\text{in. Hg})\left(\frac{0.491\ \text{lbf/in.}^2}{1\ \text{in. Hg}}\right)$$

$$= (4)(0.491)\ \text{lbf/in.}^2$$

$$= 1.96\ \text{lbf/in.}^2$$

3. U-TUBE MANOMETER No. 2



NOTES:

1. FOR INITIAL CONDIT'N (EQUILIBRIUM) $\Delta P = 0 \therefore P_{ATM} = P$.
2. SINCE h_B & h_R ARE CONSTANT, $(P_{BLUE} - P_{RED})$ IS CONSTANT.

a) DERIVATION OF P_{GAGE}

$$P_{ATM} + P_{BLUE} + P_{Hg} = P + P_{RED}$$

$$P - P_{ATM} = \Delta P = P_{Hg} + (P_{BLUE} - P_{RED})$$

$$P - P_{ATM} = P_{GAGE} \quad \therefore \quad P_{GAGE} = \Delta P$$

$$P_{GAGE} = P_{Hg} + C$$

b) DETERMINATION OF P_{Hg}

$$P_{Hg} = (h_{Hg} \text{ in. Hg})\left(\frac{0.491 \text{ lbf/in.}^2}{1 \text{ in. Hg}}\right)$$

$$= (3.7)(0.491) \text{ lbf/in.}^2$$

$$= 1.82 \text{ lbf/in.}^2$$

c) DETERMINATION OF C

$$P_{BLUE} = K\,\gamma_B\,h_B$$

$$= \left(\frac{1\ ft^3}{1728\ in.^3}\right)(62.4\ lbf/ft^3)(1.75)(3.0\ in.)$$

$$= 0.189\ lbf/in.^2$$

$$P_{RED} = \left(\frac{1\ ft^3}{1728\ in.^3}\right)(62.4\ lbf/ft^3)(0.827)(1.2\ in.)$$

$$= 0.036\ lbf/in.^2$$

$$C = P_{BLUE} - P_{RED}$$

$$= 0.189 - 0.036\ lbf/in.^2$$

$$= 0.15\ lbf/in.^2$$

d) DETERMINATION OF P_{GAGE}

$$P_{GAGE} = P_{Hg} + C$$

$$= 1.82 + 0.15\ lbf/in.^2$$

$$= 1.97\ lbf/in.^2$$

4. INCLINED MANOMETER

$$R = \text{FINAL LEVEL} - \text{INITIAL LEVEL}$$

$$= 6.85 - 1.50 \text{ in.}$$

$$= 5.35 \text{ in.}$$

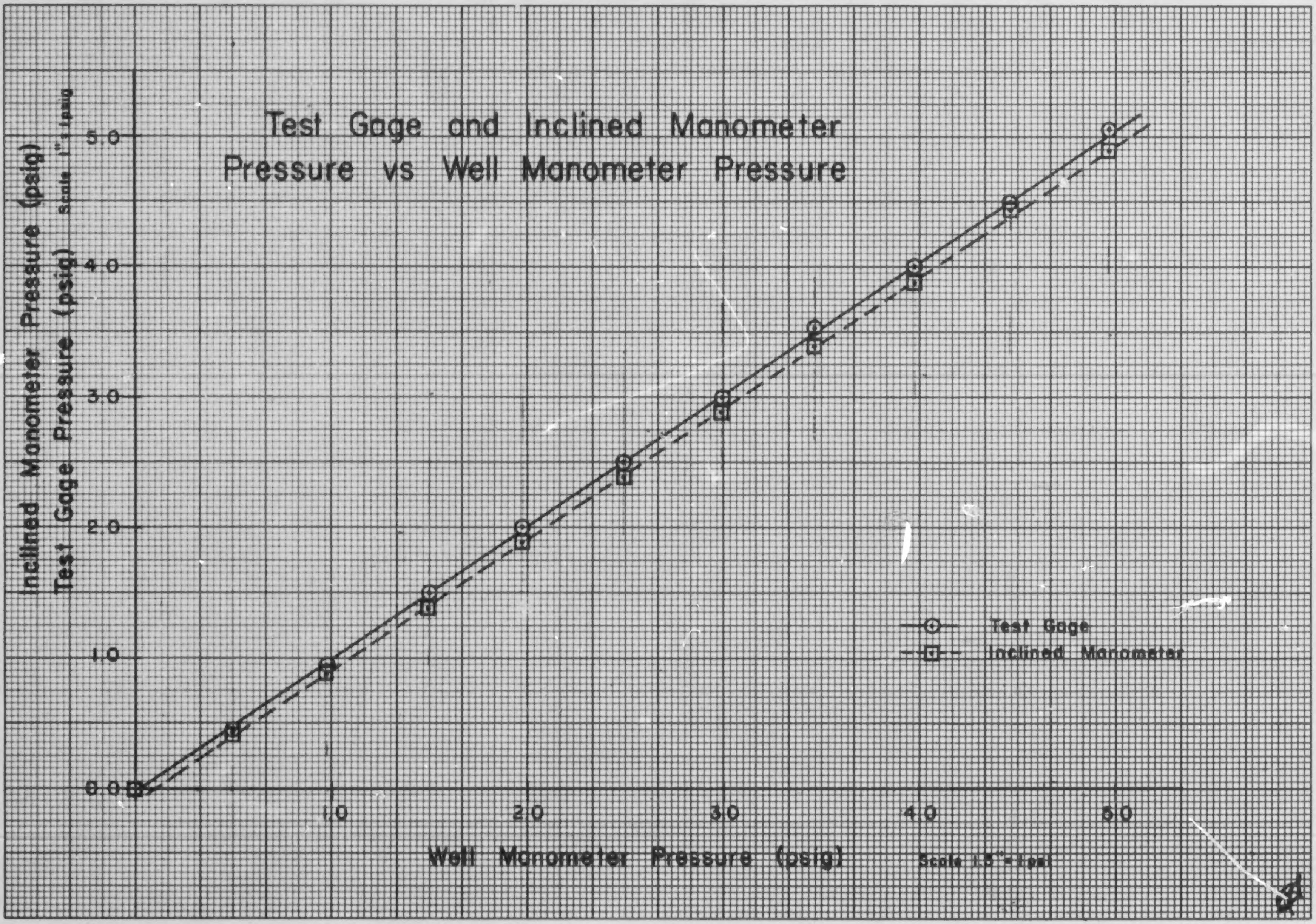
$$P = K \gamma R \left[\sin\theta + \left(\frac{d_2}{d_1}\right)^2 \right]$$

$$= \left(\frac{1 \text{ ft}^3}{1728 \text{ in}^3}\right)\left(62.4 \text{ lbf}/\text{ft}^3\right)(13.5)(5.35 \text{ in.})\left[0.707 + \left(\frac{1}{70}\right)^2\right]$$

$$= 1.89 \text{ lbf}/\text{in}^2$$

Results Sheet

Well-Type psi	No 1 U-Tube psi	No 2 U-Tube psi	Test Gage psi	Inclined psi
0.00	0.00	0.00	0.00	0.00
0.49	0.47	0.47	0.45	0.44
0.98	0.98	0.96	0.95	0.88
1.49	1.47	1.45	1.50	1.37
1.98	1.96	1.97	2.00	1.89
2.48	2.48	2.46	2.50	2.39
2.98	2.97	2.95	3.00	2.87
3.47	3.46	3.44	3.53	3.38
3.97	3.95	3.98	4.00	3.87
4.46	4.45	4.42	4.50	4.44
4.96	4.94	4.91	5.05	4.89



Test Gage and Inclined Manometer Pressure vs Well Manometer Pressure

```
      DIMENSION W(11),A1(11),A2(11),G(11),B(11),P(11),P1(11),Q(11),
     X          Q1(11),R(11),R1(11),S(11),S1(11)
C     NSF 9226 EXPERIMENT ON PRESSURE MEASUREMENTS
C               INFORMATION
C     W = WELL-TYPE MANOMETER IN INCHES OF MERCURY
C     A1 = NO. 1 U-TUBE MANOMETER IN INCHES OF MERCURY
C     A2 = NO. 2 U-TUBE MANOMETER IN INCHES OF MERCURY
C     G = TEST GAGE IN PSI
C     B = INCLINED MANOMETER IN INCHES OF MERCURY
C     P = CORRECTION FOR ZERO FOR WELL-TYPE MANOMETER
C     P1 = WELL-TYPE MANOMETER RESULTS IN PSI
C     Q = CORRECTION FOR ZERO FOR  1 U-TUBE MANOMETER
C     Q1 =  1 U-TUBE MANOMETER RESULTS IN PSI
C     R = CORRECTION FOR ZERO FOR  2 U-TUBE MANOMETER
C     R1 =  2 U-TUBE MANOMETER RESULTS IN PSI
C     S = CORRECTION FOR ZERO FOR INCLINED MANOMETER
C     S1 = INCLINED MANOMETER RESULTS IN PSI
C               DATA FORMAT
      WRITE (3,1)
      WRITE (3,2)
      WRITE (3,3)
      WRITE (3,4)
    1 FORMAT ('1',35X,'DATA'/)
    2 FORMAT (6X,'WELL-TYPE',3X,'NO 1 U-TUBE',3X,'NO 2 U-TUBE',3X,'TEST'
     X     ,1X,'GAGE',3X,'INCLINED')
    3 FORMAT (6X,'MANOMETER',4X,'MANOMETER',5X,'MANOMETER',5X,'PRESSURE'
     X        ,3X,'MANOMETER')
    4 FORMAT (6X,'INCHES HG',4X,'INCHES HG',5X,'INCHES HG',7X,'PSI',6X,
     X        'INCHES HG'/)
      READ (2,5)(W(I),A1(I),A2(I),G(I),B(I),I=1,11)
    5 FORMAT (10X,5F10.3)
C               PRINTING DATA
      WRITE (3,6)(W(I),A1(I),A2(I),G(I),B(I),I=1,11)
    6 FORMAT (8X,F5.2,8X,F5.2,9X,F5.2,8X,F5.2,7X,F5.2)
C                    CALCULATIONS
      DO 100 J=1,11
      P(J) = W(J)-1.0
      P1(J) = ((62.4*13.6)/1728.)*(P(J))
      Q(J) = A1(J)-0.1
      Q1(J) = ((62.4*13.6)/1728.)*(Q(J))
      R(J) = A2(J)-(-0.25)*.491
      R1(J) = ((62.4*13.6)/1728.)*(R(J))+((3.0*1.75*62.4/1728.)-
     X        (1.2*0.827*62.4/1728.))
C     WHERE 3.0 = HEIGHT OF BLUE LIQUID IN INCHES
C     AND 1.75 = SP.GR. OF BLUE LIQUID
C     WHERE 1.2 = HEIGHT OF RED LIQUID IN INCHES
C     AND 0.827 = SP.GR. OF RED LIQUID
      S(J) = B(J)-1.50
      S1(J) = S(J)*13.6*62.4/1728.*0.707
C     WHERE 0.707 = SINE 45 DEG
  100 CONTINUE
C               RESULT FORMAT
      WRITE (3,7)
      WRITE (3,8)
      WRITE (3,9)
      WRITE (3,10)
    7 FORMAT ('1',33X,'RESULTS'/)
    8 FORMAT (6X,'WELL-TYPE',3X,'NO 1 U-TUBE',3X,'NO 2 U-TUBE',3X,'TEST'
     X     ,1X,'GAGE',3X,'INCLINED')
    9 FORMAT (6X,'MANOMETER',4X,'MANOMETER',5X,'MANOMETER',5X,'PRESSURE'
     X        ,3X,'MANOMETER')
   10 FORMAT (8X,'PSIG',9X,'PSIG',10X,'PSIG',9X,'PSIG',8X,'PSIG'/)
```

```
C              PRINTING RESULTS
      DO 101 I=1,11
      WRITE (3,11) P1(I),Q1(I),R1(I),G(I),S1(I)
   11 FORMAT (8X,F5.2,8X,F5.2,9X,F5.2,8X,F5.2,7X,F5.2)
  101 CONTINUE
      CALL EXIT
      END
```

DATA

WELL-TYPE MANOMETER INCHES HG	NO 1 U-TUBE MANOMETER INCHES HG	NO 2 U-TUBE MANOMETER INCHES HG	TEST GAGE PRESSURE PSI	INCLINED MANOMETER INCHES HG
1.00	0.10	-0.25	0.00	1.50
2.00	0.95	0.65	0.45	2.75
3.00	2.00	1.65	0.95	4.00
4.00	3.00	2.65	1.50	5.40
5.00	4.00	3.70	2.00	6.85
6.00	5.05	4.70	2.50	8.30
7.00	6.05	5.70	3.00	9.65
8.00	7.05	6.70	3.53	11.10
9.00	8.05	7.80	4.00	12.50
10.00	9.05	8.70	4.50	14.10
11.00	10.05	9.70	5.05	15.40

RESULTS

WELL-TYPE MANOMETER PSIG	NO 1 U-TUBE MANOMETER PSIG	NO 2 U-TUBE MANOMETER PSIG	TEST GAGE PRESSURE PSIG	INCLINED MANOMETER PSIG
0.00	0.05	0.09	0.00	0.00
0.49	0.41	0.53	0.45	0.43
0.98	0.93	1.02	0.95	0.86
1.47	1.42	1.51	1.50	1.35
1.96	1.91	2.03	2.00	1.85
2.45	2.43	2.52	2.50	2.36
2.94	2.92	3.01	3.00	2.82
3.43	3.41	3.50	3.53	3.33
3.92	3.90	4.04	4.00	3.81
4.41	4.39	4.48	4.50	4.37
4.91	4.88	4.97	5.05	4.82

EXPERIMENT NO. 3

AREA MEASUREMENT

Data Sheet

Curve A

Weight Method

Trial	Weight of Square	Weight of Area
1	0.0492	0.4137
2		

Mean Ordinate Method

Average Height of Strips					
1	2	3	4	5	6
1-15/16	1-9/16	1-12/16	1-9/16	1-6/16	1-2/16
7	8	9	10	11	12
1-2/16	1-9/16	2-0	1-13/16	1-6/16	1-7/16

Data Sheet (Continued)

Curve A

Simpson's Rule Method

h	y_0	y_1	y_2	y_3	y_4	y_5
7/16	1-4/16	1-6/16	1-11/16	1-11/16	1-8/16	1-3/16
y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}
1-2/16	1-5/16	1-14/16	2-1/16	1-8/16	1-6/16	1-8/16

h - space dimension

y - ordinate height

Polar Planimeter Method

Trial	Initial Reading	Final Reading
1	0.00	8.39
2	0.00	8.35
3	0.00	8.38

SAMPLE CALCULATIONS

1. AREA (in.²) FOR CURVE `A'

a) WEIGHT METHOD

$$1\ \text{in}^2 = 0.0492\ \text{gm} \therefore \frac{1\ \text{in}^2}{0.0492\ \text{gm}} = 20.325\ \text{in}^2/\text{gm}$$

$$A = (20.325\ \text{in}^2/\text{gm})(0.4137\ \text{gm})$$

$$= 8.41\ \text{in}^2$$

b) AVERAGE HEIGHT METHOD

$$A = (\text{WIDTH})(\Sigma\ \text{AVERAGE HEIGHT OF STRIP})$$

$$= (7/16\ \text{in.})(1\text{-}5/16 + 1\text{-}9/16 + 1\text{-}12/16 + 1\text{-}9/16 + 1\text{-}6/16 + 1\text{-}2/16 + 1\text{-}2/16 + 1\text{-}9/16 + 2 + 1\text{-}13/16 + 1\text{-}6/16 + 1\text{-}7/16\ \text{in.})$$

$$= (7/16\ \text{in.})\left(\frac{288}{16}\ \text{in.}\right)$$

$$= 7.875\ \text{in}^2$$

c) SIMPSON'S RULE METHOD

$$A = \tfrac{1}{3}h\left(y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + 4y_5 + 2y_6 + 4y_7 + 2y_8 + 4y_9 + 2y_{10} + 4y_{11} + y_{12}\right) \text{ in}^2$$

$$= \tfrac{1}{3}\left(\tfrac{7}{16}\right)\left[1\cdot\tfrac{4}{16} + 4\left(1-\tfrac{6}{16}\right) + 2\left(1-\tfrac{11}{16}\right) + 4\left(1-\tfrac{11}{16}\right) + 2\left(1-\tfrac{8}{16}\right) + 4\left(1-\tfrac{3}{16}\right) + 2\left(1-\tfrac{2}{16}\right) + 4\left(1-\tfrac{5}{16}\right) + 2\left(1-\tfrac{14}{16}\right) + 4\left(2-\tfrac{1}{16}\right) + 2\left(1-\tfrac{8}{16}\right) + 4\left(1-\tfrac{6}{16}\right) + 1-\tfrac{8}{16}\right] \text{ in}^2$$

$$= \tfrac{1}{3}\left(\tfrac{7}{16}\right)\left(\frac{866}{16}\right) \text{ in}^2$$

$$= 7.89 \text{ in}^2$$

d) POLAR PLANIMETER METHOD

$$A = \frac{A_1 + A_2 + A_3}{3} \text{ in}^2$$

$$= \frac{8.39 + 8.35 + 8.38}{3} \text{ in}^2$$

$$= \frac{25.12}{3} \text{ in}^2$$

$$= 8.37 \text{ in}^2$$

2. AREA IN KW - HR.

$1\ \text{in}^2 = 2090$ Kw-hr. (SCALED FROM CURVE 'A')

a) $A = 8.41\ \text{in}^2 \left(2090\ \frac{\text{Kw-hr.}}{\text{in}^2}\right)$

$= 17{,}577$ Kw-hr.

b) $A = 7.875\ \text{in}^2\ (2090)$

$= 16460$ Kw-hr.

c) $A = 7.89\ \text{in}^2\ (2090)$

$= 16490$ Kw-hr.

d) $A = 8.37\ \text{in}^2\ (2090)$

$= 17490$ Kw-hr.

3. MEAN ORDINATE (KW)

$$\frac{17{,}577\ \text{Kw-hr.}}{24\ \text{hr.}} = 732.4\ \text{Kw}$$

Results Sheet

'A'

Method	Area (sq in)	Area (kw hr)	Mean Ordinate (kw)
Weight	8.41	17577	732
Average Height	7.88	16460	686
Simpson's Rule	7.89	16490	687
Polar Planimeter	8.37	17490	729

Data Sheet

Curve B

Weight Method

Trial	Weight of Square	Weight of Area
1	0.0492	0.4278
2		

Mean Ordinate Method

Average Height of Strips					
1	2	3	4	5	6
1-9/16	1-15/16	2-7/16	2-7/16	2-4/16	2-0
7	8	9	10	11	12
1-3/16	0-12/16	0-12/16	0-15/16	1-2/16	1-4/16

Data Sheet (Continued)

Curve B

Simpson's Rule Method

h	y_0	y_1	y_2	y_3	y_4	y_5
0-7/16	1-7/16	1-12/16	2-3/16	2-8/16	2-5/16	2-3/16
y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}
1-11/16	0-15/16	0-11/16	0-13/16	1-0	1-3/16	1-5/16

h - space dimension

y - ordinate height

Polar Planimeter Method

Trial	Initial Reading	Final Reading
1	0.00	8.75
2	0.00	8.81
3	0.00	8.72

Results Sheet

'B'

Method	Area (sq in)	Area (kw hr)	Mean Ordinate (kw)
Weight	8.70	18183	758
Average Height	8.15	17034	710
Simpson's Rule	8.17	17075	711
Polar Planimeter	8.76	18308	763

Data Sheet

Curve C

Weight Method

Trial	Weight of Square	Weight of Area
1	0.0492	0.2720
2		

Mean Ordinate Method

Average Height of Strips					
1	2	3	4	5	6
0-7/16	0-13/16	1-3/16	1-4/16	1-2/16	1-4/16
7	8	9	10	11	12
1-2/16	0-15/16	0-12/16	0-12/16	1-0	1-13/16

Data Sheet (Continued)

Curve C

Simpson's Rule Method

h	y_0	y_1	y_2	y_3	y_4	y_5
0-7/16	0-6/16	0-10/16	1-0	1-4/16	1-3/16	1-3/16
y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}
1-4/16	1-1/16	0-13/16	0-12/16	0-14/16	1-2/16	1-1/16

h - space dimension y - ordinate height

Polar Planimeter Method

Trial	Initial Reading	Final Reading
1	0.00	5.40
2	0.00	5.43
3	0.00	5.44

Results Sheet

'C'

Method	Area (sq in)	Area (kw hr)	Mean Ordinate (kw)
Weight	5.52	11554	481
Average Height	5.17	10805	450
Simpson's Rule	5.20	10868	453
Polar Planimeter	5.42	11328	472

Data Sheet

Curve D

Weight Method

Trial	Weight of Square	Weight of Area
1	0.0492	0.2595
2		

Mean Ordinate Method

Average Height of Strips					
1	2	3	4	5	6
2-1/16	1-14/16	1-2/16	0-8/16	0-4/16	0-6/16
7	8	9	10	11	12
0-11/16	0-14/16	0-12/16	0-14/16	0-14/16	0-15/16

Data Sheet (Continued)

Curve D

Simpson's Rule Method

h	y_0	y_1	y_2	y_3	y_4	y_5
0-7/16	2-0	2-1/16	1-7/16	0-11/16	0-5/16	0-4/16
y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}
0-8/16	0-15/16	0-12/16	0-13/16	0-14/16	0-14/16	1-3/16

h - space dimension y - ordinate height

Polar Planimeter Method

Trial	Initial Reading	Final Reading
1	0.00	5.14
2	0.00	5.12
3	0.00	5.14

Results Sheet

'D'

Method	Area (sq in)	Area (kw hr)	Mean Ordinate (kw)
Weight	5.27	11023	459
Average Height	5.13	10722	447
Simpson's Rule	5.12	10701	446
Polar Planimeter	5.13	10722	447

Data Sheet

Curve E

Weight Method

Trial	Weight of Square	Weight of Area
1	0.0492	0.4362
2		

Mean Ordinate Method

Average Height of Strips					
1	2	3	4	5	6
0-13/16	1-6/16	1-11/16	1-9/16	1-8/16	1-9/16
7	8	9	10	11	12
1-11/16	2-1/16	2-3/16	2-0	1-8/16	1-1/16

Data Sheet (Continued)

Curve E

Simpson's Rule Method

h	y_0	y_1	y_2	y_3	y_4	y_5
0-7/16	0-11/16	1-1/16	1-9/16	1-10/16	1-8/16	1-9/16
y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}
1-10/16	1-11/16	2-3/16	2-2/16	1-13/16	1-4/16	0-15/16

h-space dimension y-ordinate height

Polar Planimeter Method

Trial	Initial Reading	Final Reading
1	0.00	8.76
2	0.00	8.73
3	0.00	8.74

Results Sheet

'E'

Method	Area (sq in)	Area (kw hr)	Mean Ordinate (kw)
Weight	8.86	18520	772
Average Height	8.86	18517	772
Simpson's Rule	8.73	18246	760
Polar Planimeter	8.74	18267	761

EXPERIMENT NO. 4

TEMPERATURE MEASUREMENT

Data Sheet

Temp. T_1 (°F)	Temp. T_2 (°F)	Meter Reading (mv)	Gage Reading (°F)
82	75.5	1.13	94.0
90	76.0	1.35	98.0
100	77.5	1.58	107.0
110	79.0	1.81	116.0
120	81.0	2.02	126.0
130	82.5	2.25	134.0
140	85.0	2.50	144.0
150	87.0	2.78	154.0
160	88.0	3.01	163.0
170	90.5	3.28	173.0
180	92.5	3.54	183.0
190	94.5	3.78	192.5
200	96.0	4.07	202.5
210	99.5	4.32	212.0
212	107.0	4.37	214.5

Point of Immersion of T_1 40°F

Barometric Pressure 30.3 in. Hg

SAMPLE CALCULATIONS

1. TEMPERATURE CORRECTION (K)

$$K = 8.8 \times 10^{-5} D (T_1 - T_2)$$

where: D = length of emergent stem in degrees

T_1 = reading of primary thermometer

T_2 = reading of attached thermometer

K = correction in degrees

@ $T_1 = 140°F$

$T_2 = 85°F$

$D = 100°F$

$$K = 8.8 \times 10^{-5} (100°F)(140 - 85°F)$$

$$= 0.484°F$$

2. CORRECTED THERMOMETER READING

$$T = T_1 + K$$

$$= 140°F + 0.484°F$$

$$\cong 140.5°F$$

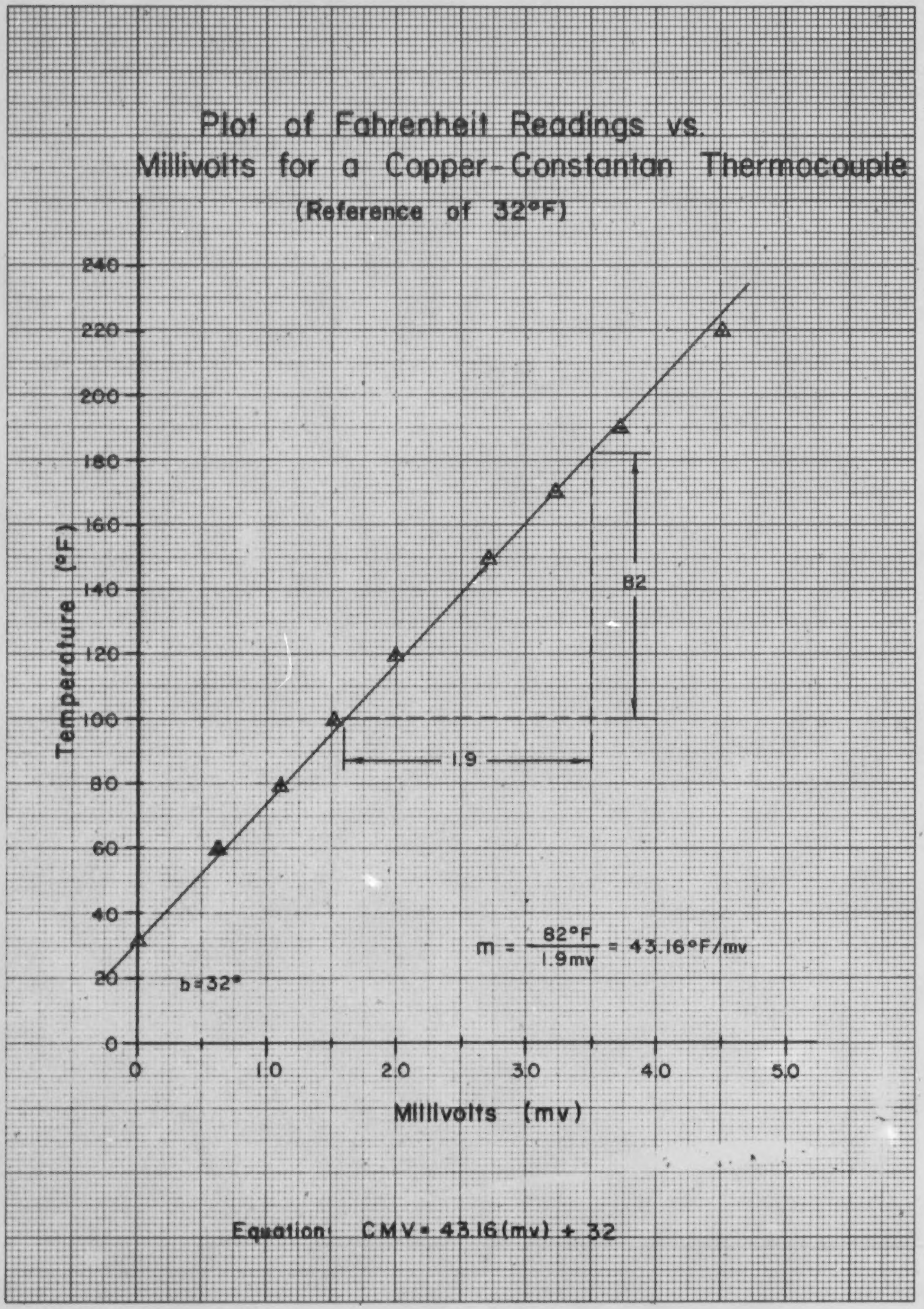
COPPER vs. CONSTANTAN THERMOCOUPLE

Degrees Fahrenheit **Reference Junction 32° F.**

°F	0	1	2	3	4	5	6	7	8	9
					Millivolts					
250	5.280	5.307	5.334	5.361	5.388	5.415	5.442	5.469	5.496	5.523
260	5.550	5.577	5.604	5.631	5.658	5.685	5.712	5.739	5.766	5.794
270	5.821	5.848	5.875	5.903	5.930	5.957	5.985	6.012	6.040	6.067
280	6.094	6.122	6.149	6.177	6.204	6.232	6.259	6.287	6.314	6.342
290	6.370	6.397	6.425	6.453	6.481	6.508	6.536	6.564	6.592	6.620
300	6.647	6.675	6.703	6.731	6.759	6.786	6.814	6.842	6.870	6.898
310	6.926	6.954	6.982	7.010	7.038	7.066	7.095	7.123	7.151	7.180
320	7.208	7.236	7.264	7.292	7.321	7.349	7.377	7.405	7.434	7.462
330	7.491	7.519	7.548	7.576	7.605	7.633	7.661	7.690	7.719	7.747
340	7.776	7.805	7.834	7.862	7.891	7.920	7.949	7.978	8.006	8.035
350	8.064	8.092	8.120	8.149	8.178	8.207	8.236	8.265	8.294	8.323
360	8.352	8.381	8.410	8.439	8.468	8.497	8.526	8.555	8.584	8.613
370	8.642	8.672	8.701	8.730	8.759	8.788	8.818	8.847	8.876	8.905
380	8.935	8.964	8.994	9.023	9.052	9.082	9.111	9.141	9.170	9.200
390	9.229	9.259	9.288	9.317	9.347	9.376	9.406	9.436	9.466	9.495
400	9.525	9.555	9.584	9.614	9.644	9.674	9.703	9.733	9.763	9.793
410	9.823	9.853	9.883	9.913	9.943	9.973	10.003	10.033	10.063	10.093
420	10.123	10.153	10.183	10.213	10.243	10.273	10.303	10.333	10.363	10.393
430	10.423	10.453	10.483	10.514	10.544	10.574	10.604	10.635	10.665	10.695
440	10.726	10.756	10.787	10.817	10.848	10.878	10.909	10.939	10.969	11.000
450	11.030	11.061	11.091	11.122	11.152	11.183	11.214	11.244	11.275	11.305
460	11.336	11.366	11.397	11.428	11.459	11.490	11.520	11.551	11.581	11.612
470	11.643	11.674	11.704	11.735	11.766	11.797	11.828	11.859	11.891	11.922
480	11.953	11.984	12.015	12.046	12.077	12.108	12.138	12.170	12.201	12.232
490	12.263	12.294	12.325	12.356	12.387	12.418	12.450	12.481	12.512	12.543
500	12.575	12.606	12.637	12.669	12.700	12.732	12.763	12.794	12.825	12.857
510	12.888	12.919	12.951	12.983	13.014	13.046	13.077	13.108	13.140	13.172
520	13.203	13.235	13.267	13.298	13.330	13.362	13.393	13.425	13.457	13.488
530	13.520	13.552	13.583	13.615	13.647	13.678	13.710	13.742	13.774	13.806
540	13.838	13.869	13.901	13.933	13.965	13.997	14.029	14.061	14.093	14.125
550	14.157	14.189	14.221	14.253	14.285	14.317	14.349	14.381	14.413	14.445
560	14.477	14.509	14.541	14.573	14.605	14.637	14.670	14.702	14.734	14.766
570	14.799	14.831	14.864	14.896	14.928	14.961	14.993	15.025	15.057	15.090
580	15.122	15.155	15.187	15.219	15.252	15.284	15.317	15.349	15.382	15.414
500	15.447	15.480	15.512	15.545	15.577	15.610	15.642	15.675	15.707	15.740
600	15.773	15.806	15.838	15.871	15.904	15.937	15.969	16.002	16.035	16.068
610	16.101	16.133	16.166	16.199	16.232	16.264	16.297	16.330	16.363	16.396
620	16.429	16.462	16.495	16.528	16.560	16.593	16.626	16.659	16.692	16.725
630	16.758	16.791	16.824	16.857	16.890	16.924	16.957	16.990	17.023	17.056
640	17.089	17.122	17.155	17.189	17.222	17.255	17.288	17.321	17.354	17.388
650	17.421	17.454	17.488	17.521	17.554	17.588	17.621	17.654	17.688	17.721
660	17.754	17.788	17.821	17.854	17.888	17.921	17.955	17.988	18.022	18.055
670	18.089	18.123	18.156	18.190	18.223	18.257	18.290	18.324	18.357	18.391
680	18.425	18.458	18.492	18.526	18.560	18.593	18.627	18.660	18.694	18.727
690	18.761	18.795	18.829	18.863	18.896	18.930	18.964	18.998	19.032	19.066
700	19.100	19.134	19.168	19.201	19.235	19.269	19.303	19.337	19.371	19.405
710	19.439	19.473	19.506	19.540	19.574	19.608	19.642	19.676	19.711	19.745
720	19.779	19.813	19.847	19.881	19.915	19.949	19.983	20.018	20.052	20.086
730	20.120	20.154	20.188	20.223	20.257	20.291	20.325	20.359	20.394	20.428
740	20.463	20.497	20.531	20.565	20.599	20.634	20.668	20.702	20.736	20.771
750	20.805	20.840	20.874	....	....	....	....	....	....	....

Results Sheets

Temp. T_1 (°F)	Correction K	Corrected Temp. (°F)	Conv. Ind. Reading (°F)	Gage Reading (°F)
82	0.024	82.0	83	94
90	0.062	90.1	93	98
100	0.119	100.1	103	107
110	0.191	110.2	112	116
120	0.274	120.3	121	126
130	0.376	130.4	131	134
140	0.484	140.5	141	144
150	0.610	150.6	153	154
160	0.760	160.8	162	163
170	0.910	170.9	173	173
180	1.08	181.1	183	183
190	1.26	191.3	193	192.5
200	1.46	201.5	204	202.5
210	1.65	211.7	214	212
212	1.59	213.6	215	214.5



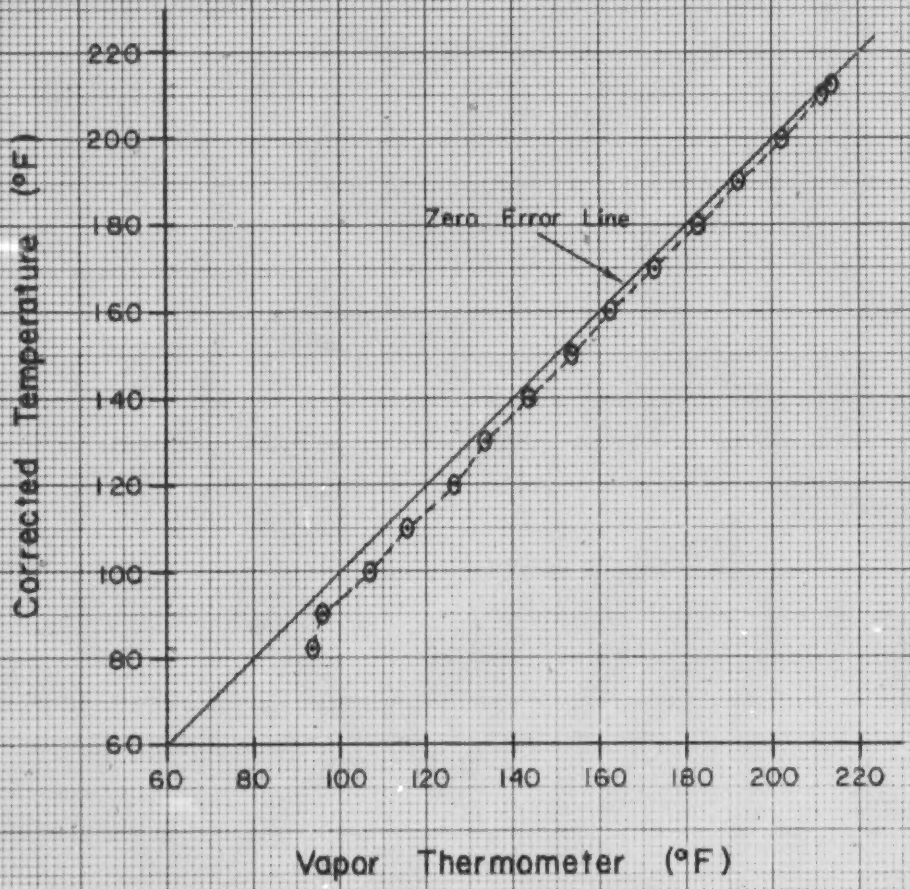
Plot of Fahrenheit Readings vs. Millivolts for a Copper-Constantan Thermocouple

(Reference of 32°F)

$m = \frac{82°F}{1.9 mv} = 43.16°F/mv$

Equation: CMV = 43.16(mv) + 32

Vapor Thermometer Temperatures vs Corrected Temperature



```
      DIMENSION T1(16),T2(16),AV(16),T3(16),C(16),CT1(16),CMV(16)
C     NSF 9226  EXPERIMENT ON TEMPERATURE MEASUREMENT
C               INFORMATION
C     T1 = GLASS THERMOMETER READINGS IN DEGREES F
C     T2 = AUXILIARY THERMOMETER READINGS IN DEGREES F
C     AV = POTENTIOMETER READINGS IN MILLIVOLTS
C     T3 = GAGE READINGS IN DEGREES F
C     C = CORRECTION FOR GLASS THERMOMETER
C     CT1 = CORRECTED GLASS THERMOMETER READINGS IN DEGREES F
C     CMV = CONVERTED POTENTIOMETER READINGS IN DEGREES F
C               DATA FORMAT
      WRITE (3,1)
      WRITE (3,2)
      WRITE (3,3)
      WRITE (3,4)
    1 FORMAT ('1',35X,'DATA'/)
    2 FORMAT (14X,'GLASS',6X,'AUXILIARY',3X,'POTENTIOMETER',
     X        3X,'TEMPERATURE')
    3 FORMAT (11X,'THERMOMETER',2X,'THERMOMETER',4X,'READINGS',
     X        5X,'GAGE READINGS')
    4 FORMAT (15X,'T1',11X,'T2',12X,'AV',12X,'DEG. F'/)
      READ(2,6)(T1(I),T2(I),AV(I),T3(I),I=1,16)
    6 FORMAT(4X,4F8.0)
C               PRINTING DATA
      WRITE(3,7)(T1(I),T2(I),AV(I),T3(I),I=1,16)
    7 FORMAT (10X,F10.3,3X,F10.3,4X,F10.3,5X,F10.3)
C               CALCULATIONS
      DO 40 J=1,16
      C(J) = 0.000088*(T1(J)-40.0)*(T1(J)-T2(J))
      CT1(J) = T1(J)+C(J)
C     EQUATION BASED ON STRAIGHT LINE RELATIONSHIP.
      CMV(J) = 43.16*AV(J)+32.0
   40 CONTINUE
C               RESULT FORMAT
      WRITE (3,8)
      WRITE (3,9)
      WRITE (3,10)
      WRITE (3,11)
    8 FORMAT ('1',34X,'RESULTS'/)
    9 FORMAT (14X,'GLASS',20X,'CORRECTED',6X,'CONVERTED')
   10 FORMAT (11X,'THERMOMETER',2X,'CORRECTION',4X,'TEMPERATURE',
     X        3X,'POTENTIOMETER')
   11 FORMAT (15X,'T1',12X,'C',12X,'CT1',7X,'READINGS. CAV'/)
C               PRINTING RESULTS
      DO 60 I=1,16
      WRITE (3,12) T1(I),C(I),CT1(I),CMV(I)
   12 FORMAT (10X,F10.3,2X,F10.3,5X,F10.3,5X,F10.3)
   60 CONTINUE
      CALL EXIT
      END
```

DATA

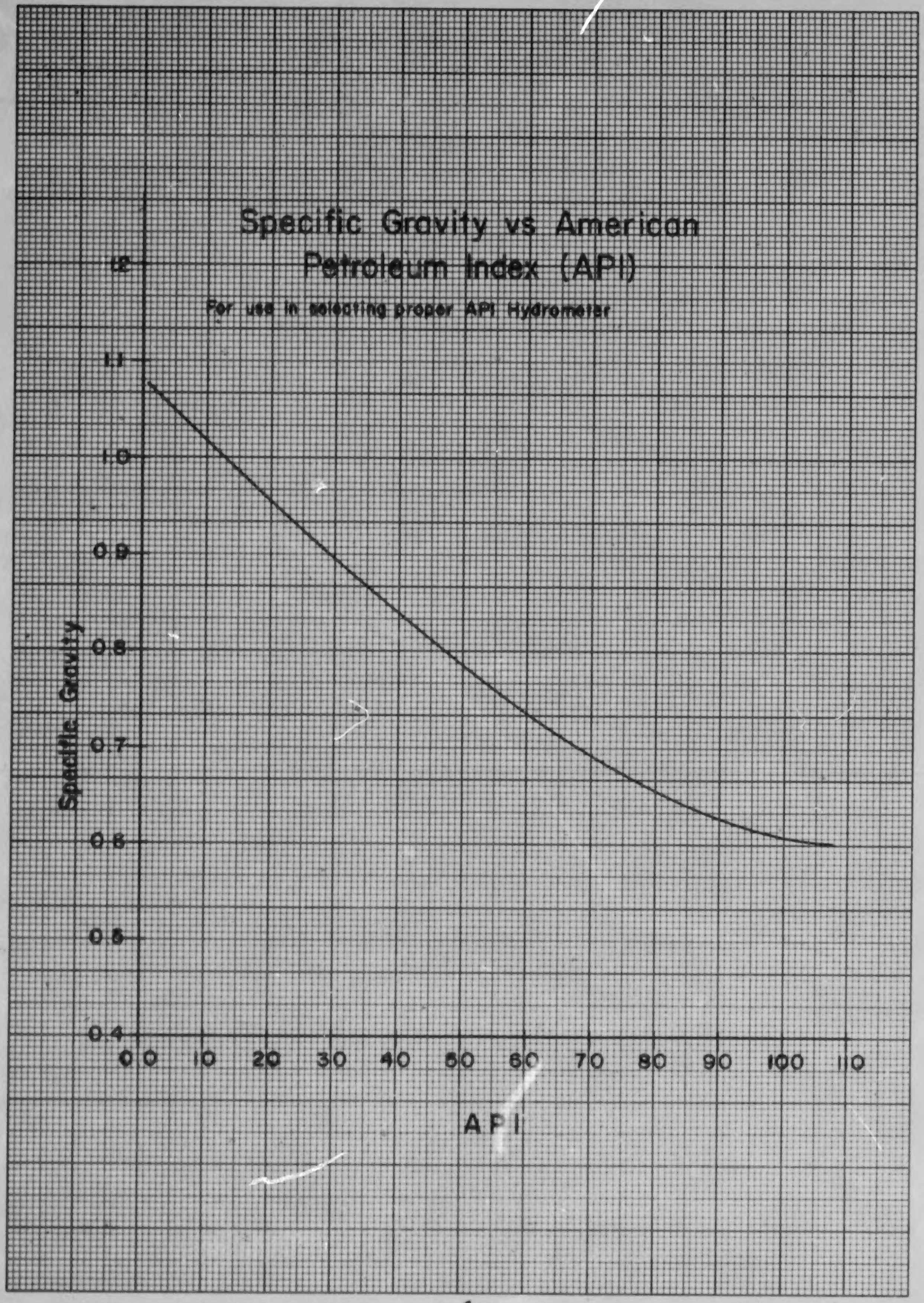
GLASS THERMOMETER T1	AUXILIARY THERMOMETER T2	POTENTIOMETER READINGS AV	TEMPERATURE GAGE READINGS DEG. F
0.000	0.000	0.000	0.000
82.000	75.500	1.130	94.000
90.000	76.000	1.350	98.000
100.000	77.500	1.580	107.000
110.000	79.000	1.810	116.000
120.000	81.000	2.020	126.000
130.000	82.500	2.250	134.000
140.000	85.000	2.500	144.000
150.000	87.000	2.780	154.000
160.000	88.000	3.010	163.000
170.000	90.500	3.280	173.000
180.000	92.500	3.540	183.000
190.000	94.500	3.780	192.500
200.000	96.000	4.070	202.500
210.000	99.500	4.320	212.000
212.000	107.000	4.370	214.500

RESULTS

GLASS THERMOMETER T1	CORRECTION C	CORRECTED TEMPERATURE CT1	CONVERTED POTENTIOMETER READINGS. CAV
0.000	0.000	0.000	32.000
82.000	0.024	82.024	80.770
90.000	0.061	90.061	90.265
100.000	0.118	100.118	100.192
110.000	0.190	110.190	110.119
120.000	0.274	120.274	119.183
130.000	0.376	130.376	129.110
140.000	0.483	140.484	139.899
150.000	0.609	150.609	151.984
160.000	0.760	160.760	161.911
170.000	0.909	170.909	173.564
180.000	1.077	181.078	184.786
190.000	1.260	191.260	195.144
200.000	1.464	201.464	207.661
210.000	1.653	211.653	218.451
212.000	1.589	213.589	220.609

EXPERIMENT NO. 5

SPECIFIC GRAVITY MEASUREMENT



Specific Gravity vs American Petroleum Index (API)

For use in selecting proper API Hydrometer

Data Sheet

Fluid		Specific Gravity		Degrees API	Temperature Degrees F
		Hydrometer	Balance		
OIL	SAE 10	0.865	0.8578	31.0	78
	Linseed	0.929	0.9335	20.4	70
	SAE 30	0.874	0.8832	29.6	77
Diesel Fuel		0.855	0.8449	34.8	72
Kerosene		0.805	0.7878	41.6	72
Tap Water		0.995	1.0420	10.5	86.5

SAMPLE CALCULATIONS

1. SPECIFIC GRAVITY (S.G.)

a) API METHOD

MEASURED API = 31.0 @ 78°F

CORRECTED API = 29.8 @ 60°F

(FROM ASTM-IP "PETROLEUM MEASUREMENT TABLES")

$$\text{S.G.} = \frac{141.5}{131.5 + \text{API @ } 60^\circ\text{F}}$$

$$= \frac{141.5}{131.5 + 29.8}$$

$$= 0.877$$

b) HYDROSTATIC BALANCE METHOD

S.G. = DIRECT BALANCE READING + APPROXIMATE CORRECTION FACTOR · (SAMPLE TEMPERATURE − 60°F)

$$= 0.8578 + 0.000295(78 - 60)$$

$$= 0.8578 + 0.0053$$

$$= 0.8631$$

2. DENSITY (ρ)

ρ IN lb/ft^3

$\rho = (\rho_{H_2O})(S.G.)$

$\rho = (62.4 \text{ lb/ft}^3)(0.8631)$

$\rho = 53.8 \text{ lb/ft}^3$

ρ IN slug/ft^3

$$\rho = (\rho \text{ lb/ft}^3)\left(\frac{1 \text{ slug}}{32.2 \text{ lb}}\right)$$

$$\rho = \frac{53.8}{32.2} \text{ slug/ft}^3$$

$\rho = 1.67 \text{ slug/ft}^3$

Results Sheets

Fluid		API	Specific Gravities			Density lb/cu.ft.	Density slugs/cu.ft.
			From API	Hydrometer	Balance		
OiL	SAE 10	29.8	0.877	0.872	0.8631	53.8	1.67
	Linseed	19.8	0.935	0.933	0.9365	58.4	1.82
	SAE 30	28.5	0.884	0.880	0.8882	55.4	1.72
Diesel Fuel		33.9	0.856	0.859	0.8484	52.9	1.64
Kerosene		40.6	0.822	0.810	0.7913	49.4	1.53
Tap Water		9.2	1.005	1.004	1.0028	62.6	1.94

All values corrected to 60°F.

EXPERIMENT NO. 6

SPEED MEASUREMENT

Data Sheet

Strobatac rpm	Tachometer rpm	Tach with Rubber Wheel	Revolution Counter	Time Seconds
2420	2480	4700	1166	30
2220	2325	4350	1073	30
2020	2110	3940	986	30
1820	1860	3500	868	30
1620	1610	3090	776	30
1420	1420	2700	685	30
1220	1200	2320	604	30
1020	1025	1930	494	30
820	820	1510	404	30

Diameter of Motor Flywheel 3.63 in.
Diameter of Rubber Wheel 1.91 in.

SAMPLE CALCULATIONS

a = RUBBER WHEEL DIA.
D = FLYWHEEL DIA.
C = FLYWHEEL CIRCUMFERENCE (πD)

1. FLYWHEEL RPM USING TACH WITH RUBBER WHEEL

$$\text{RPM} = \frac{a}{D} \times \text{DATA}\ \text{rev./min.}$$

$$= \left(\frac{1.91\ \text{in.}}{3.63\ \text{in.}}\right)\left(4700\ \text{rev./min.}\right)$$

$$= 2472\ \text{rev./min.}$$

2. FLYWHEEL RPM USING REVOLUTION COUNTER

$$\text{RPM} = \frac{\text{REVOLUTIONS}}{\text{MINUTE}}$$

$$= \frac{1166\ \text{rev.}}{30\ \text{sec.}} \times \frac{60\ \text{sec.}}{1\ \text{min.}}$$

$$= 2332\ \text{rev./min.}$$

3. PERIPHERAL SPEED OF FLYWHEEL (S)

$$S = \text{RPM} \times C = \text{RPM} \times \pi D$$

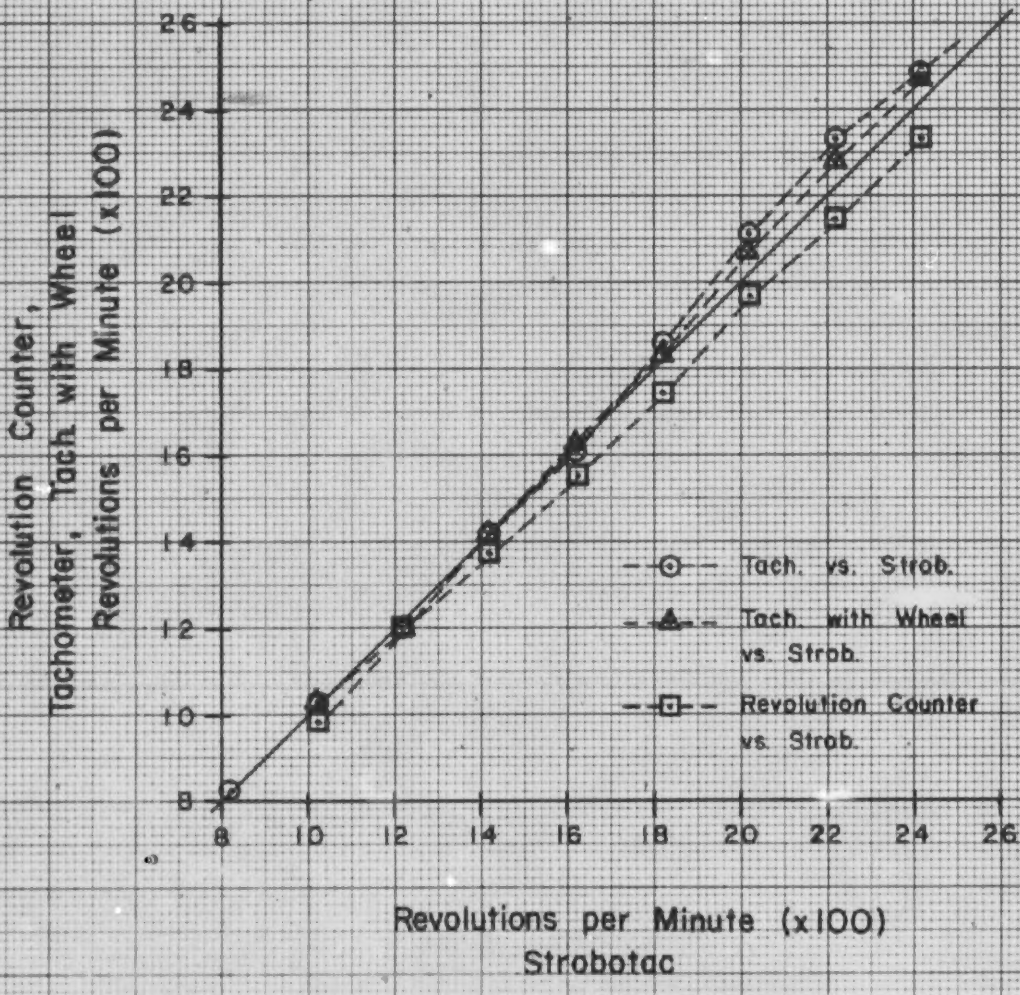
$$= \left(2420\ \text{rev./min.}\right)\left(\pi\ \frac{3.63\ \text{in./rev.}}{12\ \text{in./ft.}}\right)$$

$$= 2299\ \text{ft./min.}$$

Results Sheet

Flywheel rpm				Peripheral Speed of Flywheel ft/min
Using Strobotac	Using Tachometer	Using Rubber Wheel	Using Rev. Counter	
2420	2480	2472	2332	2299
2220	2325	2281	2146	2109
2020	2110	2072	1972	1919
1820	1860	1841	1736	1729
1620	1610	1625	1552	1539
1420	1420	1420	1370	1349
1220	1200	1220	1208	1159
1020	1025	1015	988	969
820	820	794	808	779

Tachometer, Tach with Wheel and Revolution Counter vs. Strobotac Compared to Zero Error Curve



```
      DIMENSION FS 9 ,FT 9 ,AR 9 ,AC 9 ,T 9 ,FR 9 ,FC 9 ,S 9
C     NSF 9226 EXPERIMENT ON SPEED MEASUREMENT
C                   INFORMATION
C     AR TACH WITH RUBBER WHEEL
C     AC REVOLUTION COUNTER
C     T=TIME IN SECONDS
C     D=DIAMETER OF MOTOR FLYWHEEL
C     R=DIAMETER OF RUBBER WHEEL
C     FS FLYWHEEL RPM USING STROBOTAC
C     FT FLYWHEEL RPM USING TACHOMETER
C     FR FLYWHEEL RPM USING RUBBER WHEEL
C     FC FLYWHEEL RPM USING REVOLUTION COUNTER
C     S=PERIPHERAL SPEED OF FLYWHEEL IN FT/MIN
C     C=CIRCUMFERENCE OF MOTOR FLYWHEEL
C                   DATA FORMAT
      WRITE(3,1)
    1 FORMAT 1H1,38X, DATA /
      WRITE(3,2)
    2 FORMAT 12X, FS ,12X, FT ,12X, AR ,12X, AC ,12X, T /
      DO 102 I=1,9
  100 READ 2,3 FS I ,FT I ,AR I ,AC I ,T I
    3 FORMAT(6X,5F6.1)
  102 CONTINUE
      DO 120 M=1,9
      WRITE 3,7 FS M ,FT M ,AR M ,AC M ,T M
    7 FORMAT 8X,F8.2,6X,F8.2,6X,F8.2,6X,F8.2,6X,F8.2
  120 CONTINUE
C                   CALCULATIONS
      R=1.91
      D=3.63
      C=3.14*D
C     CALCULATE RPM OF REVOLUTION COUNTER
      DO 104 J=1,9
      FC J  2*AC J
  104 CONTINUE
C     CALCULATE FLYWHEEL RPM USING RUBBER WHEEL
      DO 108 K=1,9
      FR K  AR K *R/D
  108 CONTINUE
C     CALCULATE PERIPHERAL SPEED OF FLYWHEEL(FT/MIN)
      DO 110 L=1,9
      S L  FS L *C/12.
  110 CONTINUE
C                   PRINTING RESULTS WITH HEADINGS
      WRITE 3,8
    8 FORMAT 38X, RESULTS /
      WRITE(3,6)
    6 FORMAT 12X, FS ,12X, FT ,12X, FR ,12X, FC ,12X, S /
      DO 115 N=1,9
      WRITE 3,5 FS N ,FT N ,FR N ,FC N ,S N
    5 FORMAT(8X,F8.2,6X,F8.2,6X,F8.2,6X,F8.2,6X,F8.2)
  115 CONTINUE
      CALL EXIT
      END
```

```
                                   DATA
      FS              FT              AR              AC               T

   2420.00         2480.00         4700.00         1166.00           30.00
   2220.00         2325.00         4350.00         1073.00           30.00
   2020.00         2110.00         3940.00          986.00           30.00
   1820.00         1860.00         3500.00          868.00           30.00
   1620.00         1610.00         3090.00          776.00           30.00
   1420.00         1420.00         2700.00          685.00           30.00
   1220.00         1200.00         2320.00          604.00           30.00
   1020.00         1025.00         1930.00          494.00           30.00
    820.00          820.00         1510.00          404.00           30.00
                                 RESULTS
      FS              FT              FR              FC               S

   2420.00         2480.00         2473.00         2332.00         2298.63
   2220.00         2325.00         2288.84         2146.00         2108.66
   2020.00         2110.00         2073.11         1972.00         1918.69
   1820.00         1860.00         1841.59         1736.00         1728.72
   1620.00         1610.00         1625.86         1552.00         1538.75
   1420.00         1420.00         1420.66         1370.00         1348.78
   1220.00         1200.00         1220.71         1208.00         1158.81
   1020.00         1025.00         1015.50          988.00          968.84
    820.00          820.00          794.51          808.00          778.87
```

EXPERIMENT NO. 7

PRESSURE-TEMPERATURE RELATIONSHIP

PART A

PART B

Data and Results Sheet

Part "A"

Inches Hg Vacuum	Absolute Pressure	Saturation Temperature	
		Experimental	Tables
27.0	1.43	118	114
26.0	1.92	127	125
24.0	2.90	141	140
20.0	4.87	157	161
18.0	5.85	169	169
15.0	7.32	179	179
12.0	8.81	187	187
9.0	10.27	193	194
6.0	11.74	202	200
3.0	13.22	206	206

BAROMETRIC PRESSURE : 29.9 in. Hg.

SAMPLE CALCULATIONS

1. ABSOLUTE PRESSURE

$$\text{PSIA} = (\text{BAROMETRIC PRESS. in. Hg} - \text{VACUUM in. Hg})\left(\frac{0.491\ \text{lbf/in}^2}{1\ \text{in. Hg}}\right)$$

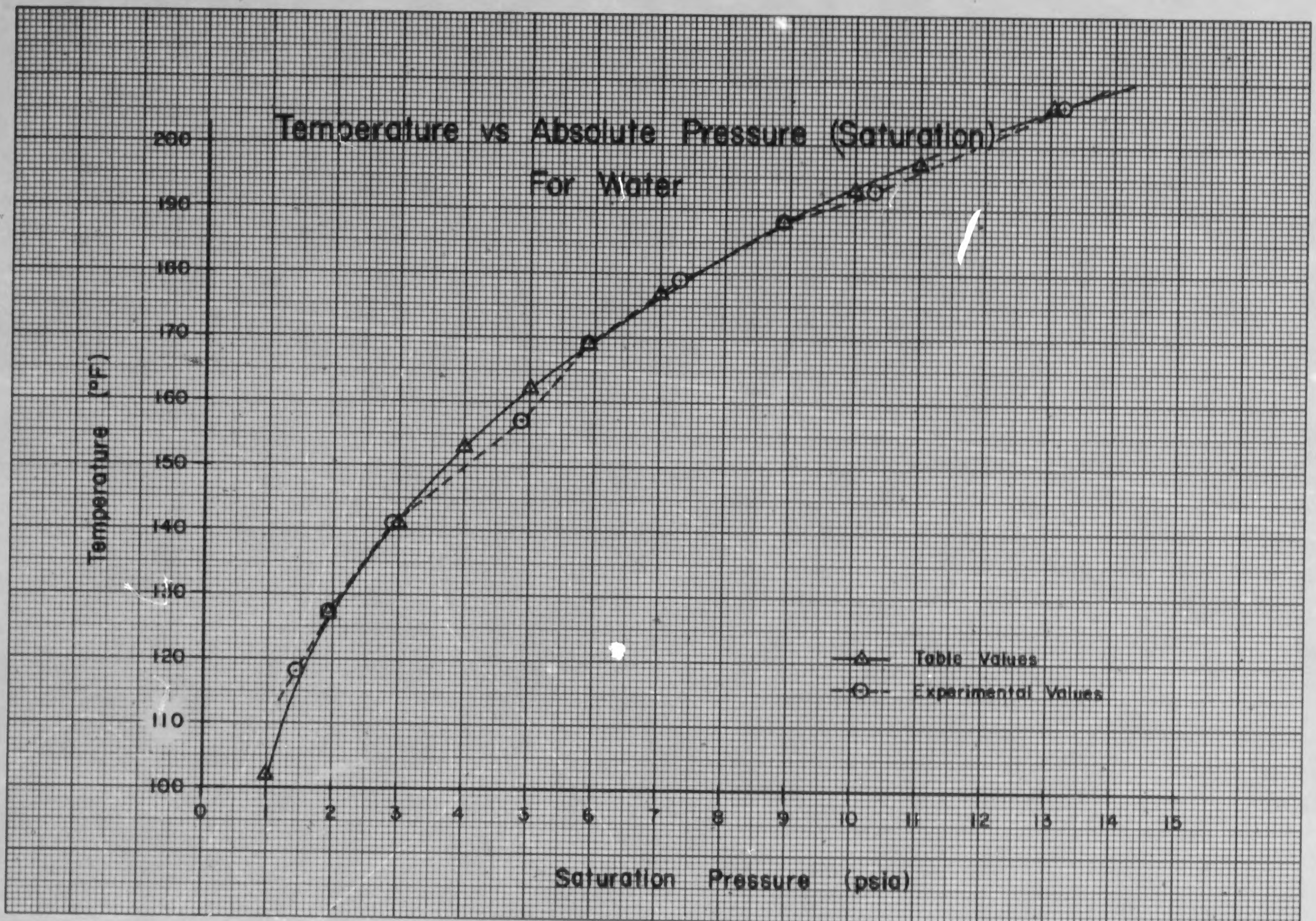
$$= (29.9 - 27.0\ \text{in. Hg})\left(0.491\ \frac{\text{PSI}}{\text{in. Hg}}\right)$$

$$= 1.43\ \text{PSIA}$$

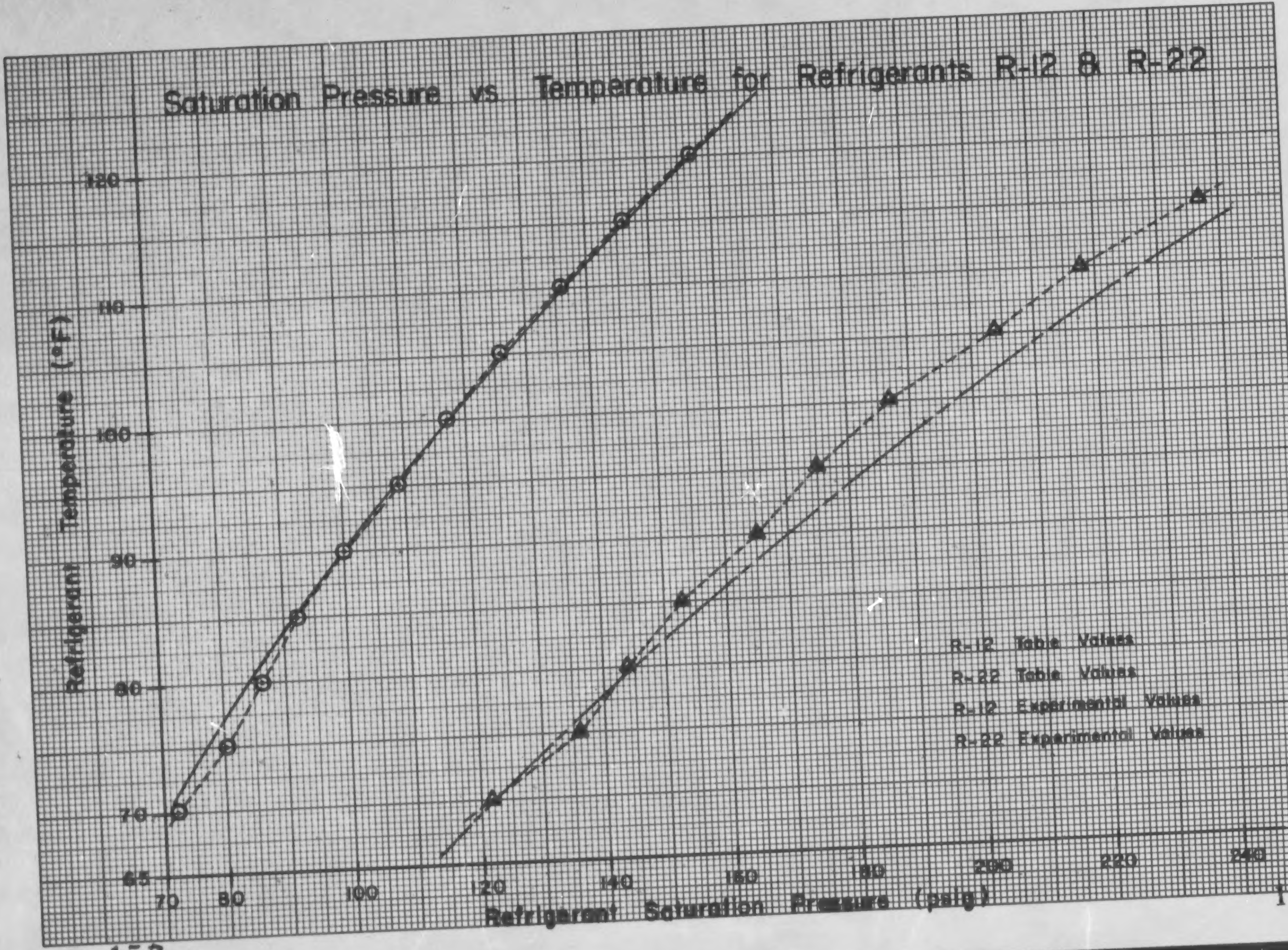
Data and Results Sheet

Part B

Bath Water Temperature degrees F	Refrigerant Pressure (psig)			
	X		Y	
	Experimental	Tabular	Experimental	Tabular
70	72	70.192	122	122.5
75	80	76.986	136	133.45
80	86	84.174	144	145
85	92	91.77	153	157.25
90	100	99.79	165	170.5
95	109	108.25	175	183.7
100	117	117.16	187	197.9
105	126	126.55	204	212.95
110	136	136.41	218	228.7
115	146	146.77	237	245.3
120	157	157.65	255	262.5



Temperature vs Absolute Pressure (Saturation)
For Water



Saturation Pressure vs. Temperature for Refrigerants R-12 & R-22

EXPERIMENT NO. 8

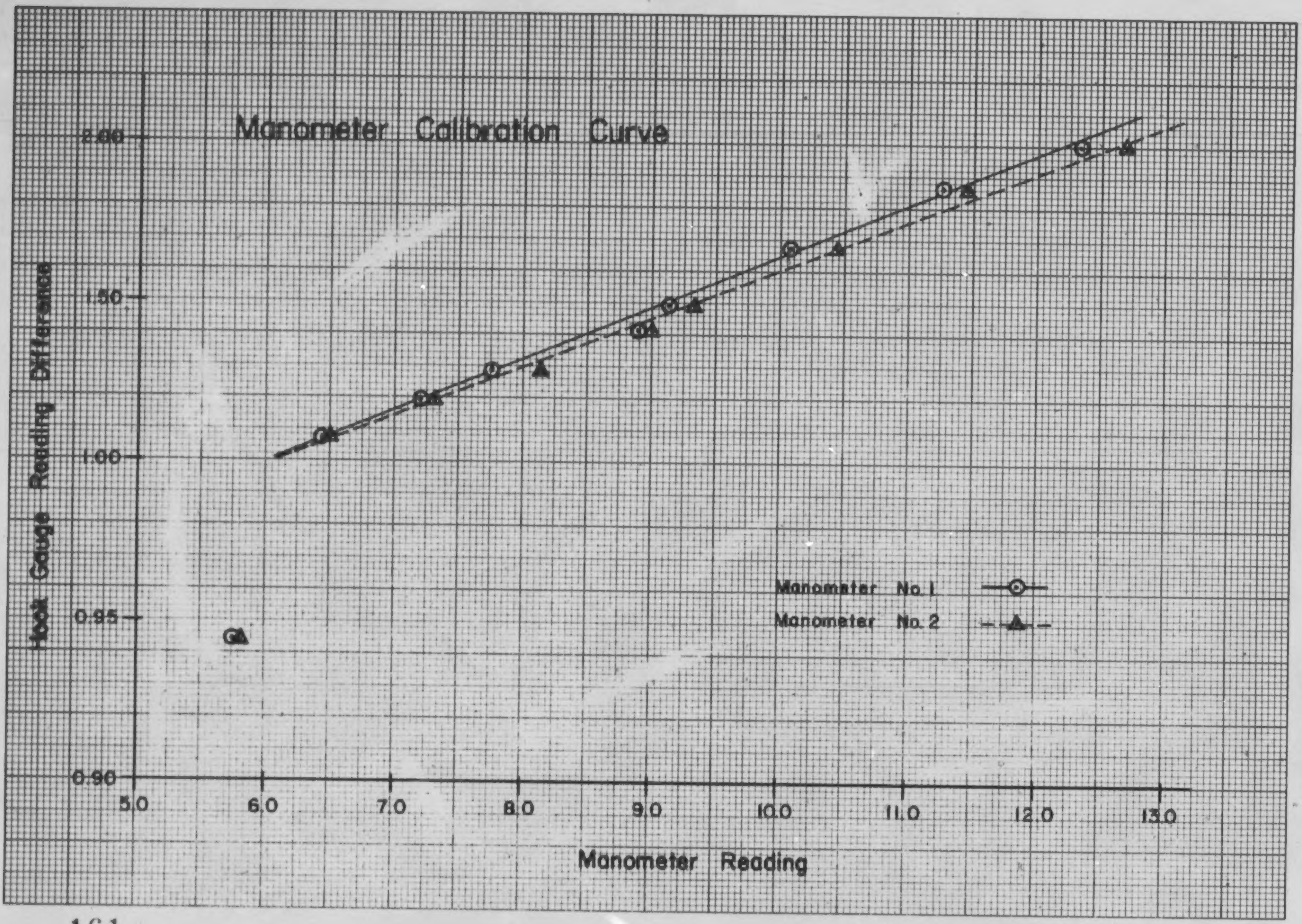
CALIBRATION OF INCLINED MANOMETER

Data and Results Sheet

Hook Gage			Manometers	
Pressure	Vacuum	Difference	No. 1	No. 2
0.473	-0.471	0.944	5 3/4	5 13/16
0.539	-0.532	1.071	6 7/16	6 8/16
0.592	-0.594	1.186	7 3/16	7 5/16
0.641	-0.639	1.280	7 3/4	8 2/16
0.705	-0.706	1.411	8 7/8	9
0.744	-0.747	1.491	9 1/8	9 5/16
0.825	-0.834	1.659	10 1/16	10 7/16
0.935	-0.921	1.856	11 1/4	11 15/16
0.995	-1.001	1.996	12 5/16	12 11/16

Barometric Pressure 29.92 in. Hg **Air Temperature** 84°F

	Manometer No. 1	Manometer No. 2
Initial Readings	0.00	0.00
Sp. Gr. of Liquids	1.00	1.00
Inclination Angle	9° 26'	9° 05'


Manometer Calibration Curve
Hook Gauge Reading Difference
2.00
1.50
1.00
0.95
0.90
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
Manometer Reading
Manometer No. 1
Manometer No. 2

EXPERIMENT NO. 9

VELOCITY MEASUREMENT

Data and Results Sheet

Fan RPM	Pitot-Tube			Mechanical Anemometer fpm			Dwyer Air Meter fpm	Alnor Velometer fpm
	Man. Read.	in. water	fpm	data	correction	Results		
1400	$4\frac{3}{16}$	0.68	3310	3500	0.90	3150	3150	3100
1300	$3\frac{3}{4}$	0.61	3130	3260	0.90	2930	2950	2890
1200	$3\frac{3}{16}$	0.52	2890	3080	0.91	2800	2700	2700
1100	$2\frac{13}{16}$	0.46	2720	2750	0.92	2530	2500	2450
1000	$2\frac{5}{16}$	0.37	2440	2480	0.93	2310	2250	2240
900	$1\frac{3}{4}$	0.28	2120	2230	0.94	2100	2000	2000
800	$1\frac{1}{8}$	0.18	1700	1940	0.95	1840	1800	1880
700	$\frac{13}{16}$	0.13	1450	1730	0.96	1650	1500	1490
600	$\frac{5}{8}$	0.10	1270	1410	0.97	1360	1200	1225
500	$\frac{1}{2}$	0.08	1140	1160	0.97	1130	1180	950

Air Temperature 72°F

Barometric Pressure 29.9 in. Hg

Specific Gravity of Manometer Fluid 1.00

Manometer scale correction factor 0.162

SAMPLE CALCULATIONS

1. PITOT TUBE VELOCITY

$$V = \sqrt{2g\,\Delta h\,\rho_2/\rho_1}$$

$$= \sqrt{(64.4\ \text{ft/sec}^2)\left(\frac{0.68}{12}\ \text{ft}\right)\left(\frac{62.4\ \text{lbm/ft}^3}{0.0746\ \text{lbm/ft}^3}\right)\left(3600\ \frac{\text{sec}^2}{\text{min}^2}\right)}$$

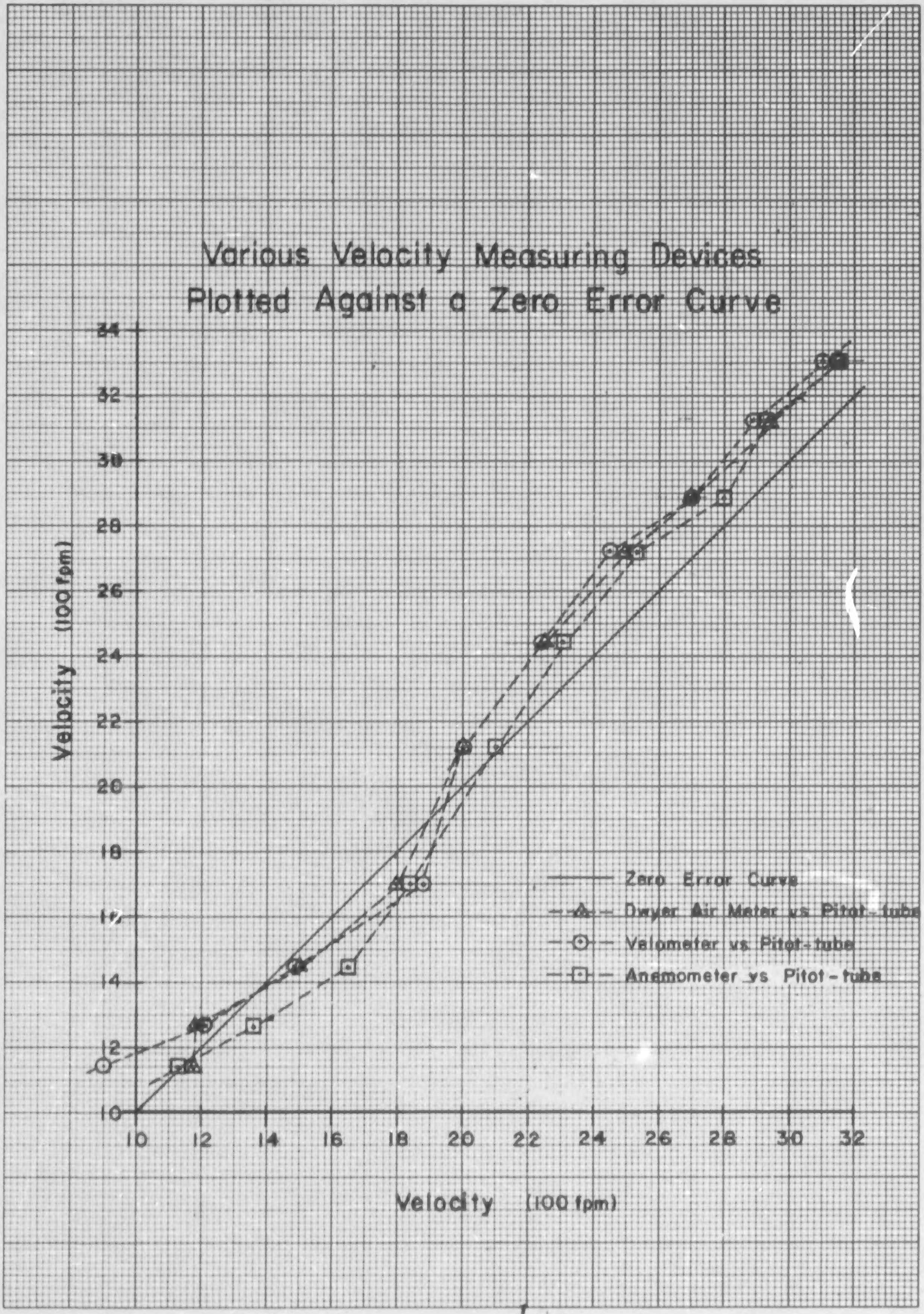
$$= 3310\ \text{ft/min.}$$

2. MECHANICAL ANEMOMETER VELOCITY

$$V = (\text{Correction Factor})(V_{\text{Read}})$$

$$= (0.90)(3500\ \text{ft/min.})$$

$$= 3150\ \text{ft/min.}$$



Various Velocity Measuring Devices Plotted Against a Zero Error Curve

EXPERIMENT NO. 10

REYNOLDS NUMBER

PART A

PART B

DATA (PART "A")

FLOW REGIME	RUN	WEIGHT (lb_f)	TIME (sec)	TEMP. (°F)
LAMINAR	1	5	285	70
	2	5	267	70
	3	5	277	70
	AVE.	5	276	70
TRANSITIONAL	1	5	214	70
	2	5	206	70
	3	5	217	70
	AVE.	5	212	70
TURBULENT	1	5	74	70
	2	5	80	70
	3	5	81	70
	AVE.	5	78	70

PIPE DIAMETER 1 in.

SAMPLE CALCULATIONS

I. LAMINAR FLOW

1. MASS FLOW RATE ($\dot{m}$)

$$\dot{m} = \frac{\text{MASS}}{\text{TIME}}$$

$$= \frac{5 \text{ lbm}}{276 \text{ sec}}$$

$$= 0.0181 \text{ lbm/sec}$$

2. VELOCITY (V)

$$\dot{m} = \rho V A$$

$$V = \frac{\dot{m}}{\rho A}$$

$$= \frac{0.0181 \text{ lbm/sec}}{(62.3 \text{ lbm/ft}^3)\left[\frac{\pi}{4}\left(\frac{1}{12}\right)^2 \text{ft}^2\right]}$$

$$= 0.0532 \text{ ft/sec}$$

3. REYNOLD'S NUMBER

$$Re = \frac{VD}{\nu}$$

$$= \frac{(0.0532 \text{ ft/sec})(1/12 \text{ ft.})}{1.059 \times 10^{-5} \text{ ft}^2\text{/sec}}$$

$$= 419$$

RESULTS (PART "A")

	FLOW REGIME		
	LAMINAR	TRANSITIONAL	TURBULENT
MASS FLOW RATE $\dot{m}$ (lb_m/sec)	0.0181	0.0236	0.0641
VELOCITY v (ft/sec)	0.0532	0.0694	0.188
REYNOLDS NUMBER	419	546	1479

Data Sheet

(Part "B")

P= 30 psig

Manometer Pressure Inches Hg.	Time seconds	Weight pounds
15.9	22.6	100
12.8	25.0	100
10.0	28.5	100
7.1	35.0	100
5.1	42.0	100
2.8	59.0	100
0.9	108.2	100

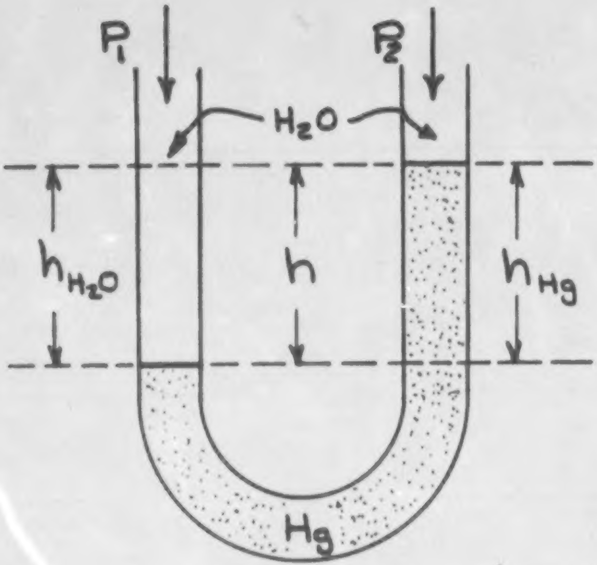
Pipe Diameter 1.0 in.

Barometer Pressure 29.9 in. Hg.

Water Temperature 82.5 °F

SAMPLE CALCULATIONS

1. PRESSURE DIFFERENCE (ΔP) IN $ft._{H_2O}$



$$h_{H_2O} = h_{Hg} = h$$

$$P_1 + h_{H_2O} = P_2 + h_{Hg}$$

$$P_1 - P_2 = h_{Hg} - h_{H_2O}$$

$$\Delta P = P_1 - P_2$$

$$= h_{Hg} - h_{H_2O}$$

$$\Delta P = (h_{Hg}\text{ in.})\left(\frac{13.6\ \frac{\text{in. }H_2O}{\text{in. }Hg}}{12\ \text{in/ft.}}\right) - (h_{H_2O}\text{ in.})\left(\frac{1\text{ ft.}}{12\text{ in.}}\right)$$

$$= h\left(\frac{13.6}{12} - \frac{1}{12}\right)\text{ ft.}_{H_2O}$$

$$= (15.9\text{ in.})\left(\frac{12.6}{12}\ \text{ft/in.}\right)$$

$$= 16.7\text{ ft.}_{H_2O}$$

2. MASS FLOW RATE

$$\dot{m} = \frac{\text{lbm}}{\text{TIME}}$$

$$= \frac{100\text{ lbm}}{22.6\text{ sec}}$$

$$= 4.42\ ^{\text{lbm}}/_{\text{sec}}$$

3. ρA = CONSTANT

$\rho A = (\rho_{H_2O}\ ^{lbm}/_{ft^3})$(CROSS SECTIONAL AREA ft^2)

$= (62.4\ ^{lbm}/_{ft^3})\left[\frac{\pi}{4}\left(\frac{1}{12}\right)^2 ft^2\right]$

$= 0.340\ ^{lbm}/_{ft}$

4. VELOCITY

$\dot{m} = \rho A V$

$$V = \frac{\dot{m}}{\rho A}$$

$$= \frac{4.42\ ^{lbm}/_{sec}}{0.340\ lbm/ft.}$$

$= 13.0\ ^{ft}/_{sec.}$

5. $\frac{\rho D}{\mu}$ = CONSTANT

$$\rho/\mu = \frac{1}{\nu}$$

$$\frac{\rho D}{\mu} = \frac{D}{\nu}$$

$$= \frac{1/12\ ft.}{0.904 \times 10^{-5}\ ft^2/sec}$$

$= 9260\ ^{sec}/_{ft}$

6. REYNOLD'S NUMBER

$$R_e = \frac{\rho V D}{\mu}$$

$$= \left(\frac{\rho D}{\mu}\right) V$$

$$= (9260 \text{ sec./ft.})(13.0 \text{ ft./sec.})$$

$$= 1.20 \times 10^5$$

Results Sheet

(Part "B")

P= 30 psig

Pressure ft. of H_2O	Mass Flow lb/sec	ρA lb/ft	Velocity ft/sec	$\rho D/\mu$ sec/ft	Reynolds No
16.7	4.42	0.340	13.0	9260	12.0×10^4
13.5	4.00	0.340	11.8	9260	10.9×10^4
10.5	3.51	0.340	10.3	9260	9.54×10^4
7.46	2.86	0.340	8.41	9260	7.79×10^4
5.36	2.38	0.340	7.00	9260	6.48×10^4
2.94	1.69	0.340	4.97	9260	4.60×10^4
0.94	0.92	0.340	2.72	9260	2.52×10^4

SAMPLE CALCULATIONS

1. DETERMINE EQUATION FOR VELOCITY IN TERMS OF REYNOLDS NUMBER

From graph V vs. Re is a straight line

$\therefore$ $V = k\,Re + b$

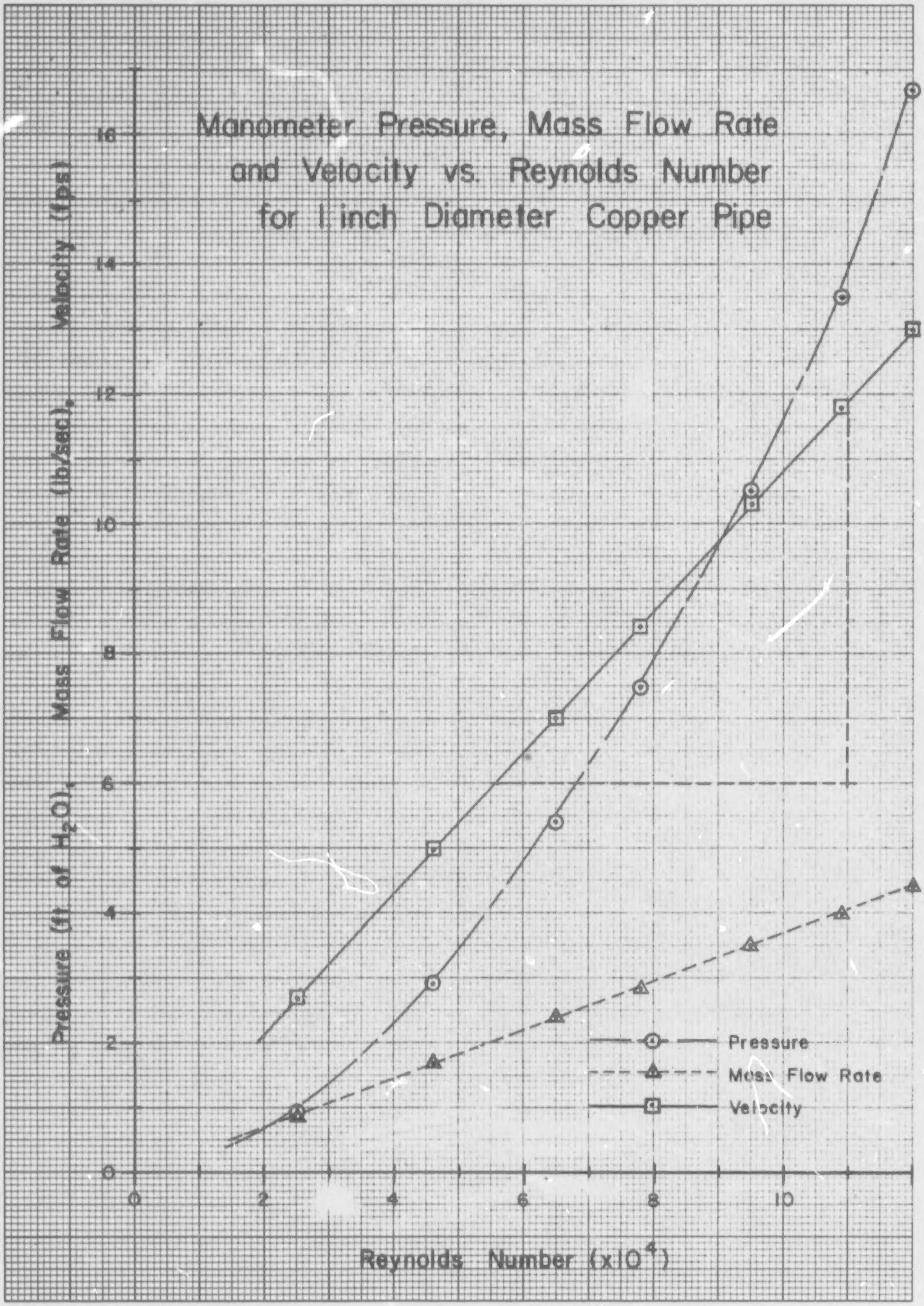
where: k = the slope
b = the intercept

$$k = \frac{\Delta V}{\Delta Re} = \frac{12-6}{(11-5.5)10^4}$$

$$= 1.09 \times 10^{-4} \text{ ft/sec}$$

$b = 0$ (thru the origin)

$$\therefore \quad V = 1.09 \times 10^{-4}\, Re \text{ ft/sec}$$


Manometer Pressure, Mass Flow Rate
and Velocity vs. Reynolds Number
for 1 inch Diameter Copper Pipe
Pressure (ft of H_2O), Mass Flow Rate (lb/sec), Velocity (fps)
0
2
4
6
8
10
12
14
16
Reynolds Number ($\times 10^4$)
0
2
4
6
8
10
Pressure
Mass Flow Rate
Velocity

EXPERIMENT NO. 11

VELOCITY PROFILE

Data Sheet

Position (inches)	Velocity Press. (in.)	
	1500 rpm	1000 rpm
0.0	0.293	0.143
0.5	0.576	0.212
1.0	0.598	0.224
1.5	0.608	0.224
2.0	0.617	0.224
2.5	0.617	0.233
3.0	0.638	0.233
3.5	0.648	0.233
4.0	0.638	0.233
4.5	0.629	0.233
5.0	0.567	0.224
5.4	0.517	0.193

Sp. Gr. of Manometer Fluid 1

Manometer Correction 0.162

Barometric Pressure 30.3 in. Hg

Air Temperature 80°F

Duct Diameter 5.75 in.

SAMPLE CALCULATIONS

1. VELOCITY

$$V = \sqrt{2g\,\Delta h\,\rho_1/\rho_2}$$

$$= \sqrt{(2)(32.2\ {}^{ft}/_{sec^2})(\Delta h\ \text{in.})\left(\frac{1\ \text{ft.}}{12\ \text{in.}}\right)\left(\frac{62.2\ \text{lbm}/\text{ft}^3}{0.0735\ \text{lbm}/\text{ft}^3}\right)}$$

$$= 67.4\sqrt{\Delta h}\ \ {}^{ft}/_{sec}$$

$$= 67.4\sqrt{0.293}\ \ {}^{ft}/_{sec}$$

$$= 36.4\ {}^{ft}/_{sec}$$

2. AVERAGE PROFILE BASE

$$\text{AVE. BASE} = \frac{\text{AREA}}{\text{DUCT DIA.}}$$

$$= \frac{29.63\ \text{in.}^2}{5.75\ \text{in.}}$$

$$= 5.15\ \text{in.}$$

$\therefore$ FROM GRAPH $V_{AVE.} = 51.5\ {}^{ft}/_{sec}$

3. COEFFICIENT (K)

$$V_{AVE} = K\,V_{MAX}$$

$$K = \frac{V_{AVE}}{V_{MAX}}$$

3. (K) CONT'D

$$K = \frac{51.5 \text{ ft/sec}}{54.2 \text{ ft/sec}}$$

$$= 0.950$$

4. REYNOLD'S NUMBER

$$Re = \frac{VD}{\nu}$$

$$= \frac{(51.5 \text{ ft/sec})\left(\frac{5.75}{12} \text{ ft}\right)}{16.9 \times 10^{-5} \text{ ft}^2/\text{sec}}$$

$$= 1.46 \times 10^5$$

5. VOLUME FLOW RATE

$$Q = AV$$

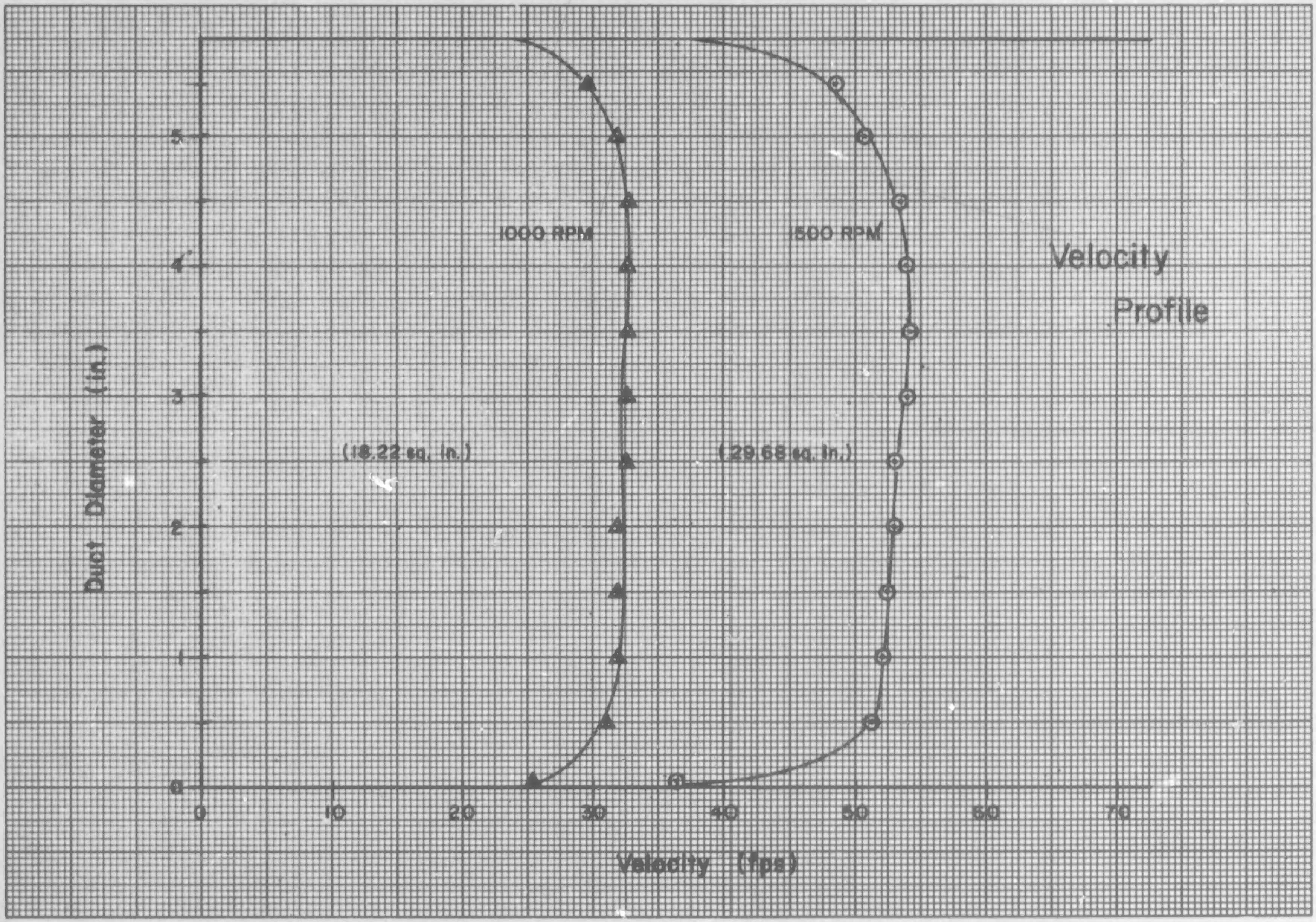
$$= \left[\frac{\pi}{4}\left(\frac{5.75}{12}\right)^2 \text{ft}^2\right](51.5 \text{ ft/sec})$$

$$= 9.27 \text{ ft}^3/\text{sec}$$

Results Sheet

Position (inches)	Velocity (ft/sec)	
	1500 rpm	1000 rpm
0.0	36.4	25.4
0.5	51.2	31.0
1.0	52.2	31.9
1.5	52.5	31.9
2.0	52.9	31.9
2.5	52.9	32.6
3.0	53.9	32.6
3.5	54.2	32.6
4.0	53.9	32.6
4.5	53.5	32.6
5.0	50.7	31.9
5.4	48.5	29.6

Fan Speed (rpm)	Profile Area (sq. in)	Ave. Base (in)	Ave. Velocity (ft/sec)	$V = KV_{max.}$	Reynolds Number	Capacity (cu ft/sec)
1500	29.63	5.15	51.5	K=0.950	1.46×10^5	9.27
1000	18.22	3.17	31.7	K=0.970	0.899×10^5	5.71


Velocity
Profile
1000 RPM
1500 RPM
(18.22 sq. in.)
(29.68 sq. in.)
Duct Diameter (in.)
0
1
2
3
4
5
Velocity (fps)
0
10
20
30
40
50
60
70

EXPERIMENT NO. 12

FLOW METERS

Data Sheet

Run Number	Weight of Water (lb)	Time (sec)	Pressure Drop		Rotameter Reading (gpm)	Water Temperature (°F)
			Orifice (in.)	Venturi (in.)		
1	50	50.9	6.9	9.7	7.6	73
2	50	55.4	5.8	7.9	7.0	73
3	50	59.7	4.9	6.8	6.5	73
4	50	65.4	4.1	5.7	6.0	73
5	50	71.2	3.4	4.8	5.5	73
6	50	78.4	2.8	4.0	5.0	73
7	50	87.5	2.3	3.2	4.5	73
8	50	99	1.9	2.5	4.0	73
9	50	114	1.3	1.9	3.5	73
10	50	133	1.0	1.4	3.0	73

Pipe Diameter 1 in.

Venturi Throat Diameter 0.625 in.

Orifice Diameter 0.688 in.

SAMPLE CALCULATIONS

1. ACTUAL FLOW THROUGH SYSTEM

a) MASS FLOW RATE ($\dot{m}$)

$$\dot{m} = \frac{\text{MASS}}{\text{TIME}}$$

$$= \frac{50 \text{ lb.}}{50.9 \text{ sec.}}$$

$$= 0.982 \text{ lb/sec.}$$

b) VELOCITY (V)

$$\dot{m} = \rho A V$$

$$V = \frac{\dot{m}}{\rho A}$$

$$= \frac{0.982 \text{ lb./sec.}}{62.4 \text{ lb/ft.}^3 \cdot \frac{\pi}{4}\left(\frac{1}{12}\right)^2 \text{ft.}^2}$$

$$= 2.89 \text{ ft./sec.}$$

c) VOLUME FLOW RATE (Q)

$$Q = VA$$

$$= 2.89 \text{ ft./sec.} \cdot \frac{\pi}{4}\left(\frac{1}{12}\right)^2 \text{ft.}^2$$

$$= 0.0158 \text{ ft.}^3\text{/sec.}$$

2. IDEAL FLOW

a) ORIFICE

$$Q_{IDEAL} = \frac{A_2}{\sqrt{1-(D_2/D_1)^4}} \cdot \sqrt{2gh}$$

$$= \frac{\frac{\pi}{4}\left(\frac{0.688}{12}\right)^2 ft^2}{\sqrt{1-\left(\frac{0.688}{1}\right)^4}} \cdot \sqrt{(2)(32.2\ \frac{ft.}{sec.^2})(\frac{6.9}{12}\ ft.)}$$

$$= 0.0179\ ft.^3/sec.$$

b) VENTURI

$$Q_{IDEAL} = \frac{A_2}{\sqrt{1-(D_2/D_1)^4}} \cdot \sqrt{2gh}$$

$$= \frac{\frac{\pi}{4}\left(\frac{0.625}{12}\right)^2 ft.^2}{\sqrt{1-\left(\frac{0.625}{1}\right)^4}} \cdot \sqrt{(2)(32.2\ \frac{ft.}{sec.^2})(\frac{9.7}{12}\ ft.)}$$

$$= 0.0168\ ft.^3/sec.$$

c) ROTAMETER

Q_{IDEAL} = CONVERSION OF GPM TO $ft.^3/sec.$

$$= 7.6\ gal./min. \times \frac{1}{60}\ min./sec \times \frac{1}{7.48}\ ft^3/gal.$$

$$= 0.0169\ ft.^3/sec.$$

3. DISCHARGE COEFFICIENT (C)

$$Q_{ACTUAL} = C Q_{IDEAL}$$

$$C = \frac{Q_{ACTUAL}}{Q_{IDEAL}}$$

a) ORIFICE

$$C = \frac{0.0158 \text{ ft.}^3/\text{sec.}}{0.0179 \text{ ft.}^3/\text{sec.}}$$

$$= 0.883$$

b) VENTURI

$$C = \frac{0.0158}{0.0168}$$

$$= 0.940$$

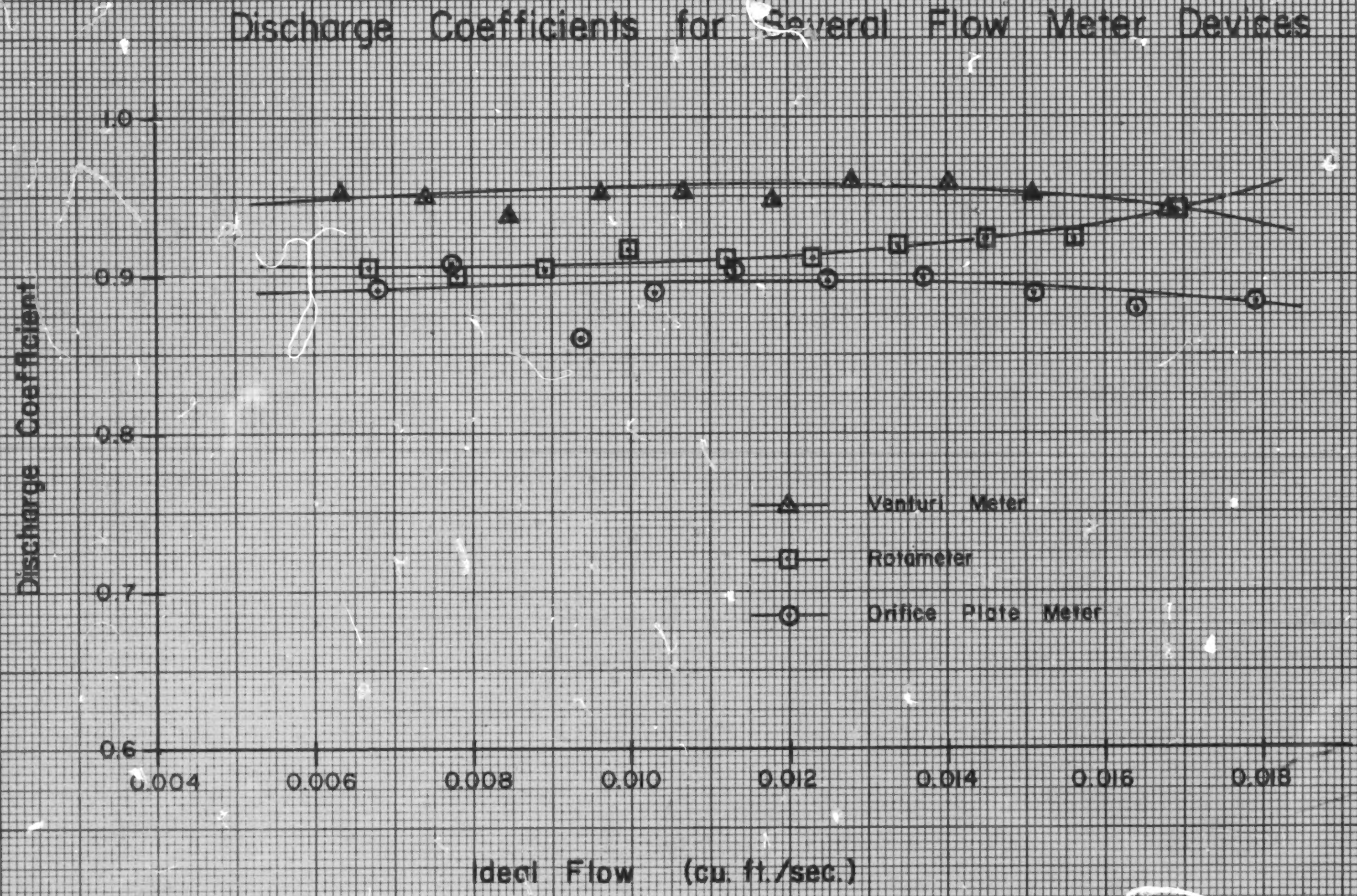
c) ROTAMETER

$$C = \frac{0.0158}{0.0169}$$

$$= 0.935$$

Results Sheet

Run Number	Actual Flow			Ideal Flow (cfs)			Coefficient "C"		
	ṁ (lb/sec)	V (fps)	Q (cfs)	Orifice	Venturi	Rotameter	Orifice	Venturi	Rotameter
1	0.982	2.89	.0158	.0179	.0168	.0169	0.883	0.940	0.935
2	0.903	2.65	.0144	.0164	.0151	.0156	0.878	0.953	0.923
3	0.837	2.46	.0134	.0151	.0140	.0145	0.887	0.957	0.924
4	0.764	2.25	.0123	.0137	.0128	.0134	0.898	0.960	0.918
5	0.702	2.06	.0112	.0125	.0118	.0123	0.896	0.948	0.911
6	0.638	1.88	.0102	.0113	.0107	.0112	0.902	0.958	0.911
7	0.571	1.68	.00916	.0103	.00961	.0100	0.889	0.953	0.916
8	0.505	1.48	.00807	.00937	.00848	.00892	0.861	0.937	0.904
9	0.439	1.29	.00703	.00774	.00741	.00781	0.908	0.949	0.900
10	0.376	1.11	.00605	.00679	.00635	.00669	0.891	0.952	0.904


Discharge Coefficients for Several Flow Meter Devices
Discharge Coefficient
1.0
0.9
0.8
0.7
0.6
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
Ideal Flow (cu. ft./sec.)
Venturi Meter
Rotameter
Orifice Plate Meter

```
      DIMENSION WT(10),T(10),PO(10),PV(10),RO(10),TEMP(10),WD(10),V(10)
     X,OR1(10),V2(10),R3(10),C1(10),C2(10),C3(10),AO(10),AV(10),Q(10)
C     NSF 9226 EXPERIMENT ON FLOWMETERS
C                INFORMATION
C     WT=WT OF WATER(LB)
C     T=TIME(SEC)
C     PO=PRESSURE DROP ACROSS ORIFICE IN INCHES OF WATER
C     PV=PRESSURE DROP ACROSS VENTURI IN INCHES OF WATER
C     RO=ROTAMETER READINGS(GPM)
C     TEMP=WATER TEMPERATURE(FAHRENHEIT)
C     WD=MASS FLOW(LB/SEC)
C     V=VELOCITY(FT/SEC)
C     Q=ACTUAL VOLUME RATE OF FLOW(CFS)
C     OR1=IDEAL VOLUME RATE OF FLOW FOR ORIFICE(CFS)
C     V2=IDEAL VOLUME RATE OF FLOW FOR VENTURI(CFS)
C     R3=IDEAL VOLUME RATE OF FLOW FOR ROTAMETER
C     C1=DISCHARGE COEFFICIENT FOR ORIFICE
C     C2=DISCHARGE COEFFICIENT FOR VENTURI
C     C3=DISCHARGE COEFFICIENT FOR ROTAMETER
      WRITE(3,4)
    4 FORMAT(1H1,33X,'DATA'/)
      READ(2,1)(WT(I),T(I),PO(I),PV(I),RO(I),TEMP(I),I=1,10)
    1 FORMAT(5X,6F10.1)
      WRITE(3,2)
    2 FORMAT(14X,'WT',9X,'T',8X,'PO',8X,'PV',8X,'RO',7X,'TEMP'/)
      WRITE(3,3)(WT(J),T(J),PO(J),PV(J),RO(J),TEMP(J),J=1,10)
    3 FORMAT(13X,F4.1,6X,F5.1,6X,F4.1,6X,F4.1,6X,F4.1,6X,F4.1/)
C                CALCULATIONS
      DO 100 J=1,10
C                CALCULATING MASS FLOW
      WD(J)=WT(J)/T(J)
C                CALCULATING VELOCITY
      V(J)=(WD(J)/(62.4*3.14159/4.*(1./12.)**2))
C                CALCULATING ACTUAL VOLUME RATE OF FLOW
      Q(J)=(V(J)*3.14/4.0*(1.0/12.0)**2.0)
C                CALCULATING IDEAL VOL RATE OF FLOW FOR ORIFICE
      AO(J)=SQRT(2.0*32.2*PO(J)/12.0)
      OR1(J)=(3.14159/4.)*(.688/12.)**2*AO(J)/SQRT(1.-(.688**4))
C                CALCULATING IDEAL VOL RATE OF FLOW FOR VENTURI
      AV(J)=SQRT(2.0*32.2*PV(J)/12.0)
      V2(J)=(3.14159/4.)*(.625/12.)**2*AV(J)/SQRT(1.-(.625**4.))
C                CALCULATING IDEAL VOL RATE OF FLOW FOR ROTAMETER
      R3(J)=RO(J)/(60.0*7.48)
C                CALCULATING DISCHARGE COEFFICIENTS
      C1(J)=Q(J)/OR1(J)
      C2(J)=Q(J)/V2(J)
      C3(J)=Q(J)/R3(J)
  100 CONTINUE
C                PRINTING RESULTS WITH HEADINGS
      WRITE(3,5)
    5 FORMAT(39X'RESULTS'/)
      WRITE(3,6)
    6 FORMAT(4X,'WD',8X,'V',7X,'Q',6X,'OR1',6X,'V2',6X,'R3',6X,'C1',6X,
     X'C2',6X,'C3'/)
      WRITE(3,7)(WD(K),V(K),Q(K),OR1(K),V2(K),R3(K),C1(K),C2(K),C3(K),K
     X 1,10
    7 FORMAT(2X,F5.3,3X,F5.3,3X,F6.4,2X,F6.4,2X,F6.4,2X,F6.4,2X,
     XF5.2,3X,F5.2,3X,F5.2/)
      CALL EXIT
      END
```

```
                                        DATA

                 WT            T            PO           PV           RO          TEMP

               50.0          50.9          6.9          9.7          7.6          73.0

               50.0          55.4          5.8          7.9          7.0          73.0

               50.0          59.7          4.9          6.8          6.5          73.0

               50.0          65.4          4.1          5.7          6.0          73.0

               50.0          71.2          3.4          4.8          5.5          73.0

               50.0          78.4          2.8          4.0          5.0          73.0

               50.0          87.5          2.3          3.2          4.5          73.0

               50.0          99.0          1.9          2.5          4.0          73.0

               50.0         114.0          1.3          1.9          3.5          73.0

               50.0         133.0          1.0          1.4          3.0          73.0

                                        RESULTS

        WD          V          Q         QR1         V2         R3         C1        C2        C3

      0.982      2.886     0.0157     0.0178     0.0166     0.0169      0.88      0.94      0.92

      0.902      2.651     0.0144     0.0163     0.0150     0.0155      0.88      0.95      0.92

      0.837      2.460     0.0134     0.0150     0.0139     0.0144      0.89      0.95      0.92

      0.764      2.246     0.0122     0.0137     0.0128     0.0133      0.89      0.95      0.91

      0.702      2.063     0.0112     0.0125     0.0117     0.0122      0.89      0.95      0.91

      0.637      1.873     0.0102     0.0113     0.0107     0.0111      0.89      0.95      0.91

      0.571      1.678     0.0091     0.0102     0.0095     0.0100      0.88      0.95      0.91

      0.505      1.483     0.0080     0.0093     0.0084     0.0089      0.86      0.95      0.90

      0.438      1.288     0.0070     0.0077     0.0073     0.0077      0.90      0.95      0.90

      0.375      1.104     0.0060     0.0067     0.0063     0.0065      0.88      0.94      0.90
```

EXPERIMENT NO. 13

LOST HEAD IN PIPES AND FITTINGS

Data Sheet

Sta. No.	Fittings	Manometer Readings (inches of Hg)			
		1	2	3	4
1	4-45° elbows & 7.53ft of pipe	4.2	5.5	6.8	7.7
2	14.73ft of pipe	5.7	7.5	9.2	10.5
3	2-90° elbows & 8.75ft of pipe	3.9	5.1	6.4	7.3
4	Check Valve & 5.48ft of pipe	2.4	3.2	4.0	4.4
5	Gate Valve & 5.48ft of pipe	2.6	3.4	4.2	4.7
6	Globe Valve & 5.56ft of pipe	12.0	16.0	20.0	23.0
Time (seconds)		62	54.5	47.2	43.5
Water Temperature		74	74	74	74
Weight of water		200	200	200	200

Pipe Diameter 1/12 feet

SAMPLE CALCULATIONS

1. MASS FLOW RATE (lbm/sec)

$$\dot{m} = \frac{200\ \text{lbm}}{62.0\ \text{sec}}$$

$$= 3.23\ \text{lbm/sec}$$

2. FLOW VELOCITY (ft/sec)

$$\dot{m} = \rho V A$$

$$V = \frac{\dot{m}}{\rho A}$$

$$= \frac{3.23\ \text{lbm/sec}}{(62.3\ \text{lbm/ft}^3)\left(\frac{\pi}{4}\left[1/12\right]^2\ \text{ft}^2\right)} = 9.50\ \text{ft/sec}$$

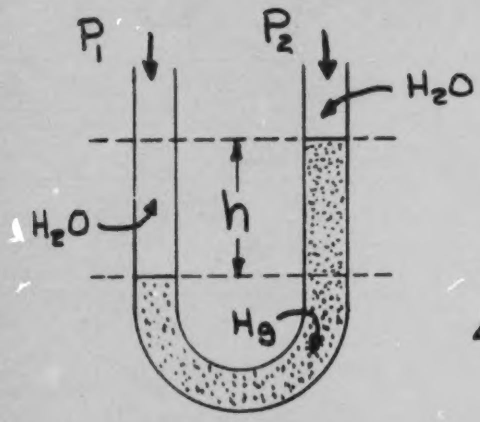
3. REYNOLDS NUMBER

$$Re = \frac{\rho V D}{\mu} = \frac{V D}{\nu}$$

$$= \frac{(9.50\ \text{ft/sec})\left(\frac{1}{12}\ \text{ft}\right)}{1.008 \times 10^{-5}\ \text{ft}^2/\text{sec}}$$

$$= 7.85 \times 10^{4}$$

4. LOST HEAD FOR STRAIGHT PIPE (ft. of H_2O)



$$P_1 + h''_{H_2O} = P_2 + h''_{Hg}$$

$$\Delta P = P_1 - P_2 = h''_{Hg} - h''_{H_2O}$$

CONVERTING TO ft. OF WATER:

$$\Delta P = (h''_{Hg})\left(13.6\,\frac{\text{in. } H_2O}{\text{in. } Hg}\right)\left(\frac{1}{12}\ \text{ft/in.}\right) - (h''_{H_2O})\left(\frac{1}{12}\ \text{ft/in.}\right)$$

NOTE: $h''_{Hg} = h''_{H_2O} = h''$

$$\Delta P = (5.7\ \text{in.})\left[(13.6)\left(\frac{1}{12}\right) - \left(\frac{1}{12}\right)\ \text{ft/in.}\right]$$

$$= (5.7\ \text{in.})\left[1.05\ \text{ft/in } H_2O\right]$$

$$= 5.99\ \text{ft. } H_2O$$

h = LOST HEAD = ΔP

$= 5.99$ ft. H_2O

5. LOST HEAD PER FOOT OF PIPE

$$\frac{h}{L} = \frac{5.99\ \text{ft. } H_2O}{14.73\ \text{ft. PIPE}}$$

$$= 0.407\ \frac{\text{ft. } H_2O}{\text{ft. PIPE}}$$

6. LOST HEAD FOR ONE 45° ELBOW ($\text{ft. } H_2O$)

a) LOST HEAD FOR (4) 45° ELBOWS AND 7.53 ft. OF PIPE

$$h = (4.2 \text{ in.})(1.05 \text{ ft/in. } H_2O)$$

$$= 4.41 \text{ ft. } H_2O$$

b) LOST HEAD FOR (1) 45° ELBOW

$$h = \frac{(4.41 \text{ ft } H_2O) - \left[(7.53 \text{ ft. PIPE})(0.407 \frac{\text{ft. } H_2O}{\text{ft. PIPE}})\right]}{4}$$

$$h = 0.338 \text{ ft. } H_2O$$

7. LOST HEAD FOR ONE 90° ELBOW ($\text{ft. } H_2O$)

a) LOST HEAD FOR (2) 90° ELBOWS AND 8.75 ft. OF PIPE

$$h = (3.9 \text{ in.})(1.05 \frac{\text{ft. } H_2O}{\text{in.}})$$

$$= 4.10 \text{ ft. } H_2O$$

b) LOST HEAD FOR (1) 90° ELBOW

$$h = \frac{(4.10 \text{ ft. } H_2O) - \left[(8.75 \text{ ft. PIPE})(0.407 \frac{\text{ft. } H_2O}{\text{ft. PIPE}})\right]}{2}$$

$$h = 0.270 \text{ ft. } H_2O$$

8. LOST HEAD FOR ONE CHECK VALVE (ft. H_2O)

a) LOST HEAD FOR (1) CHECK VALVE AND 5.48 ft. OF PIPE

$$h = (2.4 \text{ in.})(1.05 \text{ ft/in. } H_2O)$$

$$= 2.52 \text{ ft. } H_2O$$

b) LOST HEAD FOR (1) CHECK VALVE

$$h = 2.52 \text{ ft. } H_2O - \left[(5.48 \text{ ft. PIPE})\left(0.407 \frac{\text{ft. } H_2O}{\text{ft. PIPE}}\right)\right]$$

$$= 0.29 \text{ ft. } H_2O$$

9. LOST HEAD FOR ONE GATE VALVE (ft. H_2O)

a) LOST HEAD FOR (1) GATE VALVE AND 5.48 ft. OF PIPE

$$h = (2.6 \text{ in.})(1.05 \text{ ft/in. } H_2O)$$

$$= 2.73 \text{ ft. } H_2O$$

b) LOST HEAD FOR (1) GATE VALVE

$$h = 2.73 \text{ ft. } H_2O - \left[(5.48 \text{ ft. PIPE})\left(0.407 \frac{\text{ft. } H_2O}{\text{ft. PIPE}}\right)\right]$$

$$= 0.50 \text{ ft. } H_2O$$

10. LOST HEAD FOR ONE GLOBE VALVE (ft. H_2O)

a) LOST HEAD FOR (1) GLOBE VALVE AND 5.56 ft. OF PIPE

$$h = (12.0 \text{ in.})(1.05 \text{ ft/in. } H_2O)$$

$$= 12.6 \text{ ft. } H_2O$$

b) LOST HEAD FOR (1) GLOBE VALVE

$$h = 12.6 \text{ ft. } H_2O - \left[(5.56 \text{ ft. PIPE})\left(0.407 \frac{\text{ft. } H_2O}{\text{ft. PIPE}}\right)\right]$$

$$= 10.3 \text{ ft. } H_2O$$

11. INTERFERENCE COEFFICIENT (K)

$$h = K \frac{V^2}{2g}$$

$$K = \frac{h\,2g}{V^2}$$

a) K FOR (1) 45° ELBOW

$$K = \frac{(0.338 \text{ ft. } H_2O)(64.4 \text{ ft/sec}^2)}{(9.50 \text{ ft/sec})^2}$$

$$= 0.241$$

12. FRICTION FACTOR (f)

$$h = f \frac{L}{D} \frac{V^2}{2g}$$

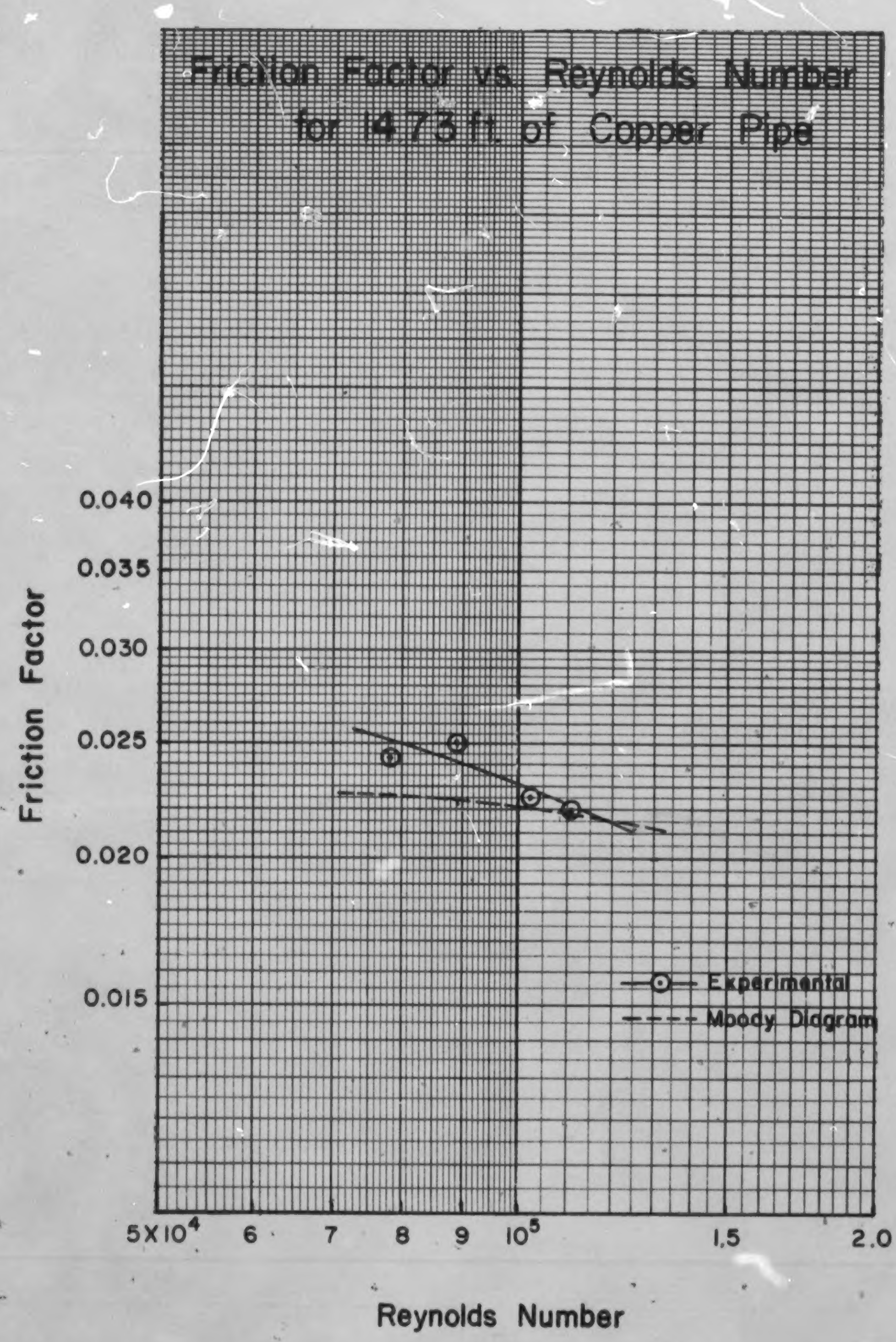
$$f = \left(\frac{h}{L}\right) D \frac{2g}{V^2}$$

$$= \left(0.407 \frac{\text{ft } H_2O}{\text{ft PIPE}}\right)\left(\frac{1}{12} \text{ ft}\right) \frac{(64.4 \text{ ft/sec}^2)}{(9.50 \text{ ft/sec})^2}$$

$$= 0.0242$$

Results Sheet

Test		1	2	3	4
Mass-Flow-Rate lb/sec		3.23	3.67	4.23	4.60
Flow Velocity fps		9.50	10.8	12.5	13.5
Reynolds Number		7.85×10^4	8.92×10^4	10.3×10^4	11.1×10^4
Lost Head ft of water	14.73 ft pipe	5.99	7.87	9.66	11.0
	per foot of pipe	0.407	0.534	0.656	0.746
Lost Head - feet of water	45° elbow	0.338	0.437	0.548	0.615
	90° elbow	0.270	0.340	0.490	0.570
	Check Valve	0.290	0.430	0.600	0.530
	Gate Valve	0.500	0.640	0.810	0.850
	Globe Valve	10.30	13.80	17.30	20.00
Interference Coefficient K	1-45° elbow	0.241	0.241	0.225	0.217
	1-90° elbow	0.193	0.188	0.201	0.202
	Check Valve	0.207	0.236	0.247	0.188
	Gate Valve	0.357	0.353	0.333	0.300
	Globe Valve	7.36	7.62	7.13	7.07
Frict. Factor	14.73 ft pipe	0.0242	0.0250	0.0225	0.0220


Friction Factor vs. Reynolds Number for 14.73 ft. of Copper Pipe

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      DIMENSION A1(4),A2(4),A3(4),A4(4),A5(4),A6(4),T(4),WT(4),W(4),V(4)
     X,RE 4 ,H1 4 ,H2 4 ,C1 4 ,C2 4 ,C3 4 ,C4 4 ,C5 4 ,P1 4 ,P2 4 ,
     XP3 4 ,P4 4 ,P5 4 ,F 4
C     NSF 9226 EXPERIMENT ON LOST HEAD
C                INFORMATION
C     A1=DEL. P FOR 4-45DEG. ELBOWS AND 7.53 FT OF PIPE IN IN. OF HG.
C     A2=DEL. P FOR 14.73 FT OF PIPE IN IN. OF HG.
C     A3=DEL. P FOR 2-90DEG. ELBOWS AND 8.75 FT OF PIPE IN IN. OF HG.
C     A4=DEL. P FOR CHECK VALVE AND 5.48 FT OF PIPE IN IN. OF HG.
C     A5=DEL. P FOR GATE VALVE AND 5.48 FT OF PIPE IN IN. OF HG.
C     A6=DEL. P FOR GLOBE VALVE AND 5.56 FT OF PIPE IN IN. OF HG.
C     T=TIME IN SECONDS
C     WT=WEIGHT OF WATER COLLECTED IN POUNDS
C     W=MASS-FLOW-RATE IN POUNDS/SEC.
C     RE=REYNOLDS NUMBER
C     H1=LOST HEAD FOR 14.73 FT OF PIPE IN FT OF WATER
C     H2=LOST HEAD PER FOOT OF PIPE IN FT OF WATER
C     C1=INTERFERENCE COEFFICIENTS FOR A 45DEG. ELBOW
C     C2=INTERFERENCE COEFFICIENTS FOR A 90DEG. ELBOW
C     C3=INTERFERENCE COEFFICIENTS FOR A CHECK VALVE
C     C4=INTERFERENCE COEFFICIENTS FOR A GATE VALVE
C     C5=INTERFERENCE COEFFICIENTS FOR A GLOBE VALVE
C     P1=LOST HEAD FOR A 45DEG. ELBOW IN FT. OF WATER
C     P2=LOST HEAD FOR A 90DEG. ELBOW IN FT. OF WATER
C     P3=LOST HEAD FOR A CHECK VALVE IN FT OF WATER
C     P4=LOST HEAD FOR A GATE VALVE IN FT OF WATER
C     P5=LOST HEAD FOR A GLOBE VALVE IN FT OF WATER
C     F=FRICTION FACTOR FOR A STRAIGHT RUN OF COPPER PIPE
C     V=VELOCITY IN FT/SEC
C                DATA FORMAT
      READ(2,4)(A1(K),A2(K),A3(K),A4(K),A5(K),A6(K),T(K),WT(K),K=1,4)
    4 FORMAT(5X,8F5.1)
      WRITE(3,1)
    1 FORMAT(1H1,38X,'DATA'/)
      WRITE(3,2)
    2 FORMAT(9X,'MANOMETER READINGS IN INCHES OF HG.',11X,'TIME',3X,
     X WEIGHT /
      WRITE(3,3)
    3 FORMAT(8X,'A1',5X,'A2',5X,'A3',5X,'A4',5X,'A5',5X,'A6',10X,'SEC',
     -4X,'LBS'/)
      WRITE(3,5)(A1(M),A2(M),A3(M),A4(M),A5(M),A6(M),T(M),WT(M),M=1,4)
    5 FORMAT(7X,F4.1,3X,F4.1,3X,F4.1,3X,F4.1,3X,F4.1,3X,F4.1,9X,F4.1,
     X3X,F4.0,/
C                CALCULATIONS
      DO 100 J=1,4
      W(J)=WT(J)/T(J)
      V(J)=W(J)/((62.4*.785*(1.0/12.0)**2.0))
      RE J    V J *.083/1.008E-05
C                CALCULATING FOR LOST HEAD
      H1(J)=A2(J)*((13.6/12.0)-(1.0/12.0))
      H2(J)=H1(J)/14.73
      P1 J    A1 J *1.05-H2 J *7.53 /4.0
      P2 J    A3 J *1.05-H2 J *8.75 /2.0
      P3 J     A4 J *1.05-H2 J *5.48
      P4 J     A5 J *1.05-H2 J *5.48
      P5 J     A6 J *1.05-H2 J *5.56
C                CALCULATING INTERFERENCE COEFFICIENTS
      C1(J)=((P1(J)*2.0*32.2))/((V(J)**2.0))
      C2(J)=((P2(J)*2.0*32.2))/((V(J)**2.0))
      C3(J)=((P3(J)*2.0*32.2))/((V(J)**2.0))
      C4(J)=((P4(J)*2.0*32.2))/((V(J)**2.0))
      C5(J)=((P5(J)*2.0*32.2))/((V(J)**2.0))
```

```
C                   CALCULATING FOR FRICTION FACTOR
      F(J)=H2(J)*1.0/12.0*2.0*32.2/V(J)**2.0
  100 CONTINUE
C                   PRINTING RESULTS WITH HEADINGS
      WRITE(3,6)
    6 FORMAT(1H1,34X,'RESULTS'/)
      WRITE(3,7)
    7 FORMAT(10X,'W',12X,'V',13X,'RE',13X,'H1',12X,'H2'/)
      WRITE(3,8)(W(I),V(I),RE(I),H1(I),H2(I),I=1,4)
    8 FORMAT(7X,F6.4,7X,F6.3,8X,F8.1,8X,F6.3,8X,F6.4/
      WRITE(3,9)
    9 FORMAT(8X,'P1',11X,'P2',13X,'P3',13X,'P4',12X,'P5'/)
      WRITE(3,10)(P1(L),P2(L),P3(L),P4(L),P5(L),L=1,4)
   10 FORMAT(7X,F6.4,7X,F6.4,9X,F6.4,9X,F6.4,8X,F8.4,/
      WRITE(3,11)
   11 FORMAT(6X,'C1',10X,'C2',10X,'C3',10X,'C4',10X,'C5',10X,'F'/)
      WRITE(3,12)(C1(N),C2(N),C3(N),C4(N),C5(N),F(N),N=1,4)
   12 FORMAT(5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4/
      CALL EXIT
      END
```

DATA

MANOMETER READINGS IN INCHES OF HG.						TIME	WEIGHT
A1	A2	A3	A4	A5	A6	SEC	LBS
4.2	5.7	3.9	2.4	2.6	12.0	62.0	200.
5.5	7.5	5.1	3.2	3.4	16.0	54.5	200.
6.8	9.2	6.4	4.0	4.2	20.0	47.2	200.
7.7	10.5	7.3	4.4	4.7	23.0	43.5	200.

RESULTS

W	V	RE	H1	H2
3.2258	9.483	78084.3	5.985	0.4063
3.6697	10.788	88829.9	7.875	0.5346
4.2372	12.456	102568.4	9.660	0.6558
4.5977	13.516	111292.6	11.024	0.7484

P1	P2	P3	P4	P5
0.3376	0.2698	0.2934	0.5034	10.3408
0.4373	0.3385	0.4302	0.6402	13.8274
0.5504	0.4908	0.6061	0.8161	17.3537
0.6122	0.5579	0.5183	0.8333	19.9884

C1	C2	C3	C4	C5	F
0.2417	0.1932	0.2101	0.3605	7.4054	0.0242
0.2419	0.1873	0.2380	0.3542	7.6514	0.0246
0.2284	0.2037	0.2515	0.3387	7.2025	0.0226
0.2158	0.1966	0.1827	0.2937	7.0464	0.0219

EXPERIMENT NO. 14

CENTRIFUGAL PUMP

Data Sheet

At 3500 rpm

Discharge Pressure (psig)	Suction Pressure (in. Hg)	Volts	Amps	Weight (lbs.)	Time (sec.)
44	8.0	490	4.60	100	22.75
45	7.5	490	4.45	100	25.0
46	7.0	490	4.40	100	27.5
47	6.4	490	4.22	100	33.25
48	5.8	490	4.15	100	45.5
49	5.2	490	4.00	100	79.0

Pipe Sizes: Inlet Diameter 1.5 in.

Outlet Diameter 1.0 in.

Barometric Pressure 29.92 in.Hg

Water Temperature 80°F

Gage Location from Pump Center Line:

Discharge Line 36 in.

Suction Line 16 in.

SAMPLE CALCULATIONS

1. TOTAL DISCHARGE HEAD (H_{TD})

$$H_{TD} = h_{s2} + h_{v2} + z_2$$

a) STATIC HEAD (h_{s2})

$$h_{s2} = \frac{P_s}{\gamma}$$

$$= \frac{(44\ \text{lbf/in}^2)(144\ \text{in}^2/\text{ft}^2)}{62.2\ \text{lbf/ft}^3}$$

$$= 101.8\ \text{ft.}$$

b) VELOCITY HEAD (h_{v2})

$$h_{v2} = \frac{V_2^2}{2g} \qquad V_2 = \frac{\dot{m}}{\rho_2 A_2}$$

$$= \frac{(100\ \text{lbm})/(22.75\ \text{sec})}{(62.2\ \text{lbm/ft}^3)(\frac{\pi}{4}[\frac{1}{12}]^2\ \text{ft}^2)}$$

$$= 12.96\ \text{ft/sec}$$

$$h_{v2} = \frac{(12.96\ \text{ft/sec})^2}{(64.4\ \text{ft/sec}^2)}$$

$$= 2.61\ \text{ft.}$$

c) ELEVATION HEAD (z_2)

$$z_2 = \frac{36\ \text{in.}}{12\ \text{in./ft.}}$$

$$= 3\ \text{ft.}$$

$$H_{TD} = h_{s2} + h_{v2} + Z_2$$

$$= 101.8 \text{ ft.} + 2.61 \text{ ft.} + 3 \text{ ft.}$$

$$= 107.4 \text{ ft.}$$

2. TOTAL SUCTION HEAD (H_{TS})

$$H_{TS} = h_{s1} + h_{v1} + Z_1$$

a) STATIC HEAD (h_{s1})

$$h_{s1} = \frac{P_s}{\gamma}$$

$$= \frac{(-8 \text{ in. Hg})(0.491 \text{ lb/in}^2/\text{in. Hg})(144 \text{ in}^2/\text{ft}^2)}{62.2 \text{ lbf/ft}^3}$$

$$= -9.08 \text{ ft.}$$

b) VELOCITY HEAD (h_{v1})

$$h_{v1} = \frac{V_1^2}{2g} \qquad V_1 = \frac{\dot{m}}{\rho_1 A_1}$$

$$= \frac{100 \text{ lbm}/22.75 \text{ sec}}{(62.2 \text{ lbm/ft}^3)\left[\frac{\pi}{4}\left(\frac{1.5}{12}\right)^2 \text{ ft}^2\right]}$$

$$= 5.75 \text{ ft/sec}$$

$$h_{v1} = \frac{(5.75 \text{ ft/sec})^2}{64.4 \text{ ft/sec}^2}$$

$$= 0.513 \text{ ft.}$$

c) ELEVATION HEAD (Z_1)

$$Z_1 = \frac{16}{12} \text{ ft.}$$

$$= 1.33 \text{ ft.}$$

$$H_{TS} = h_{S1} + h_{V1} + Z_1$$

$$= -9.08 \text{ ft.} + 0.513 \text{ ft.} + 1.33 \text{ ft.}$$

$$= -7.23 \text{ ft.}$$

3. TOTAL HEAD (H_T)

$$H_T = H_{TS} - H_{TD} - \cancelto{0}{h_f}$$

$$= -7.23 - 107.4$$

$$= -114.6 \text{ ft.}$$

4. WATER HORSEPOWER (HHP)

$$HHP = \frac{\dot{W} H_T}{550}$$

$$= \frac{(100 \text{ lb}/22.75 \text{ sec})(114.6 \text{ ft.})}{550 \ \frac{\text{ft.-lb./sec}}{\text{HP}}}$$

$$= 0.916 \text{ HP}$$

5. INPUT TO MOTOR (W_{IN})

$$W_{IN} = \frac{(\text{VOLTS})(\text{AMPS})\sqrt{3}}{1000}$$

$$= \frac{(490)(4.6)\sqrt{3}}{1000}$$

$$= 3.90 \text{ KW}$$

6. MOTOR AND DRIVE EFFICIENCY ($\eta_{M\&D}$)

From manufacturer's performance curve
@ 3.90 kw input.

$$\eta_{M\&D} = 52\%$$

7. HORSEPOWER OUTPUT OF MOTOR (BHP)

$$BHP_{OUT} = (W_{IN} \text{ KW})(\eta_{M\&D})(1.341 \text{ HP/KW})$$

$$= (3.90 \text{ KW})(0.52)(1.341 \text{ HP/KW})$$

$$= 2.72 \text{ HP}$$

8. PUMP EFFICIENCY (η_{PUMP})

$$\eta_{PUMP} = \frac{HHP}{BHP} \times 100\%$$

$$= \frac{0.916}{2.72} \times 100\%$$

$$= 33.7\%$$

9. PUMP CAPACITY (GPM)

$$Q = \frac{\dot{m}}{\rho}$$

$$= \left(\frac{100 \text{ lb}}{22.75 \text{ sec}}\right)\left(60 \frac{\text{sec}}{\text{min}}\right)\left(\frac{1}{62.2 \text{ lb/ft}^3}\right)\left(7.48 \text{ gal/ft}^3\right)$$

$$= 31.7 \text{ GPM}$$

10. SPECIFIC SPEED (η_s)

$$\eta_s = \frac{N\sqrt{Q}}{(H_T)^{3/4}}$$

$$= \frac{3500\sqrt{31.7}}{(114.6)^{3/4}}$$

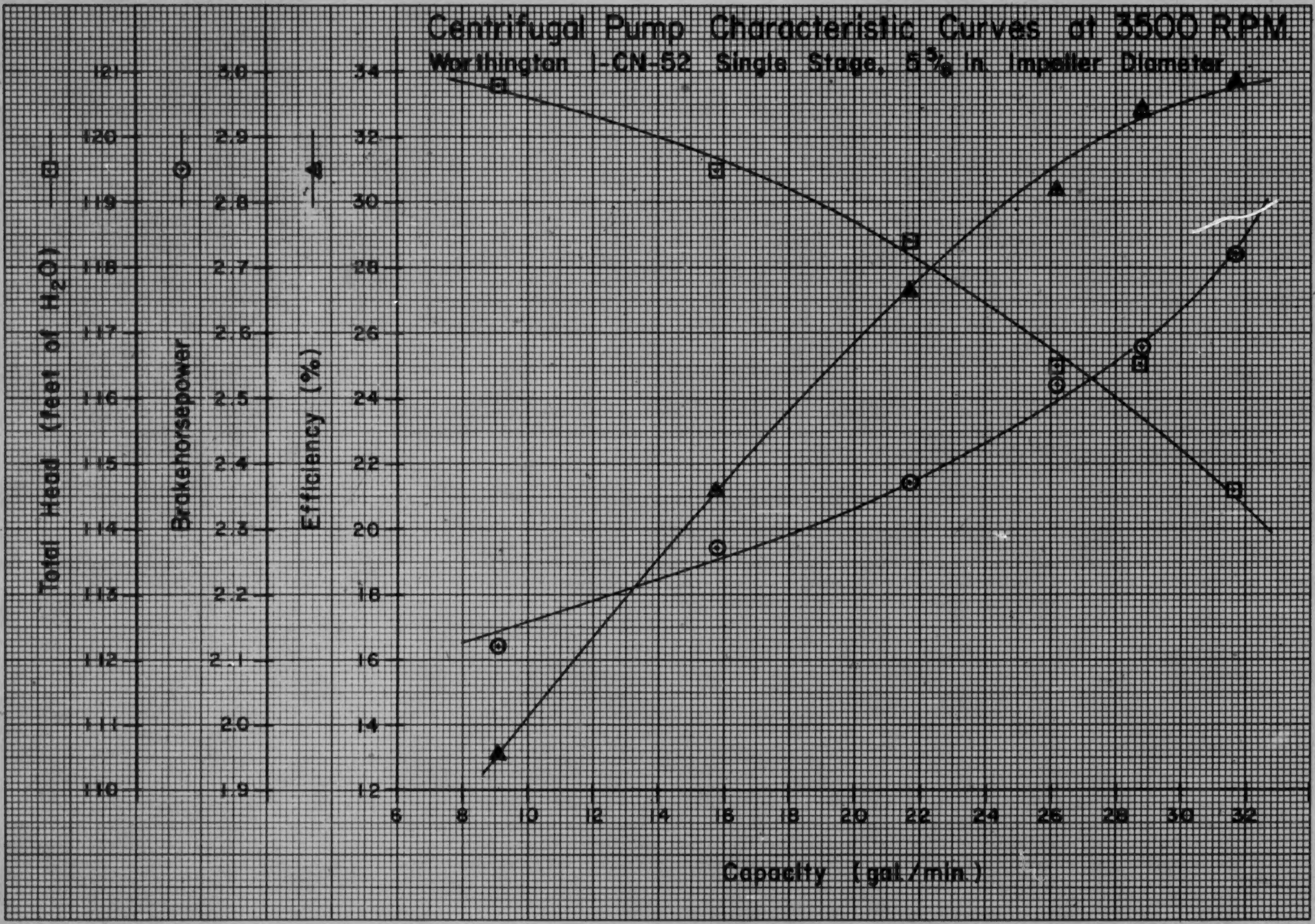
$$= 563$$

Results Sheet

Total Disch. Head (feet)	Total Suct. Head (feet)	Total Head (feet)	Water Horsepower	Motor			Pump Efficiency	Capacity (gal/min)
				KW Input	Efficiency* η	HP Output		
107.4	-7.23	-114.6	0.916	3.90	0.520	2.72	33.7 %	31.7
109.3	-7.19	-116.5	0.846	3.77	0.510	2.58	32.8	28.8
110.6	-5.94	-116.5	0.770	3.73	0.505	2.53	30.4	26.2
113.0	-5.37	-118.4	0.647	3.58	0.493	2.37	27.3	21.7
114.7	-4.78	-119.5	0.478	3.52	0.483	2.27	21.1	15.8
116.6	-4.20	-120.8	0.277	3.39	0.467	2.12	13.1	9.11

Specific Speed 563

* Efficiency of Vari-Drive Unit including Power Factor


Centrifugal Pump Characteristic Curves at 3500 R.P.M.
Worthington 1-CN-52 Single Stage, 5 5/8 in. Impeller Diameter
Total Head (feet of H2O)
Brakehorsepower
Efficiency (%)
Capacity (gal./min.)
121
120
119
118
117
116
115
114
113
112
111
110
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
34
32
30
28
26
24
22
20
18
16
14
12
6
8
10
12
14
16
18
20
22
24
26
28
30
32

```
      WRITE(3,5001)
 5001 FORMAT(1H1,24X,'CENTRIFUGAL PUMP EXPERIMENT'/)
      WRITE(3,5002)
 5002 FORMAT(10X,'DISCH',6X,'SUCT',5X,'TOTAL',5X,'WATER',5X,'INPUT',
     16X,'PUMP',2X,'CAPACITY'/11X,3('HEAD',6X),'H.P.',6X,'(HP)',7X,
     2'EFF (GAL/MIN)'/11X,3('(FT)',6X,),19X,'(PCT)'/)
      W=100.
      RO=62.2
C     ELEVATION HEAD SUCTION FEET
      Z1=1.33
C     ELEVATION HEAD DISCHARGE FEET
      Z2=3.0
C     CALCULATE INLET LINE AREA
      A1=0.0123
C     CALCULATE DISCHARGE LINE AREA
      A2=0.00545
      DO5004 I=1,6
      READ(2,5003)DP,SP,AMP,TME,ETTA
 5003 FORMAT(5F10.0)
      V1=W/(RO*TME*A1)
      V2=W/(RO*TME*A2)
      HV1=(V1**2.)/64.4
      HV2=(V2**2.)/64.4
      SH=-(SP*1.136)
      DH=DP*2.31
      HTS=HV1+Z1+SH
      HTD=HV2+Z2+DH
      TH=HTD-HTS
      HPIN=490.*AMP*1.73/1000.*ETTA*1.341
      HYHP=W*TH/(550*TME)
      EFF=(HYHP/HPIN)*100.
      CAP=448.8*W/(62.2*TME)
 5004 WRITE(3,5005)HTD,HTS,TH,HYHP,HPIN,EFF,CAP
 5005 FORMAT(9X,F6.1,4X,F6.2,4X,F6.1,4X,F6.3,4X,F6.2,4X,F6.1,4X,F6.1)
      CALL EXIT
      END
```

CENTRIFUGAL PUMP EXPERIMENT

DISCH HEAD (FT)	SUCT HEAD (FT)	TOTAL HEAD (FT)	WATER H.P.	INPUT (HP)	PUMP EFF (PCT)	CAPACITY (GAL/MIN)
107.2	-7.24	114.4	0.915	2.71	33.6	31.7
109.1	-6.76	115.8	0.842	2.57	32.6	28.8
111.0	-6.27	117.3	0.775	2.52	30.7	26.2
112.7	-5.70	118.4	0.647	2.36	27.3	21.7
114.5	-5.13	119.6	0.478	2.27	20.9	15.8
116.4	-4.53	120.9	0.278	2.12	13.1	9.1

EXPERIMENT NO. 15

FAN TESTING AND PERFORMANCE

DATA

SPEED OF FAN = 1800 RPM

DUCT EXIT SETTING	MOTOR INPUT		AIR TEMP.	MANOMETER READING		CORRECTED MAN. RDG.*	
				ACROSS ORIFICE	UPSTREAM STATIC PRESS.	ACROSS ORIFICE Δh	UPSTREAM STATIC PRESS. P_s
	VOLTS	AMPS	°F	IN H_2O	IN H_2O	IN H_2O	IN H_2O
OPEN	89	1.69	82	12-7/16	7-6/16	2.02	1.23
.9	89	1.67	82	12-1/16	7-7/16	1.95	1.24
.8	89	1.64	82	11-6/16	7-8/16	1.84	1.25
.7	88	1.63	82	10-9/16	7-9/16	1.71	1.26
.6	87	1.60	82	9-3/16	7-10/16	1.49	1.27
.5	87	1.58	82	7-13/16	7-11/16	1.26	1.28
.4	85	1.54	83	6-4/16	8-2/16	1.01	1.36
.3	83	1.50	83	4-4/16	8-10/16	0.69	1.44
.2	82	1.48	83	2-3/16	9-3/16	0.36	1.53
.1	80	1.44	83	0-7/16	9-10/16	0.07	1.61
CLOSED	82	1.49	83	0-0	10-9/16	0.00	1.76

* CORRECTED MAN. RDG. = MANOMETER READING X MANOMETER SCALE FACTOR

ORIFICE DIAMETER, d = 3.40 IN   ORIFICE COEFFICIENT, Cd = 0.661

DUCT DIAMETER, D = 5.75 IN   BAROMETRIC PRESSURE = 30.0 IN Hg

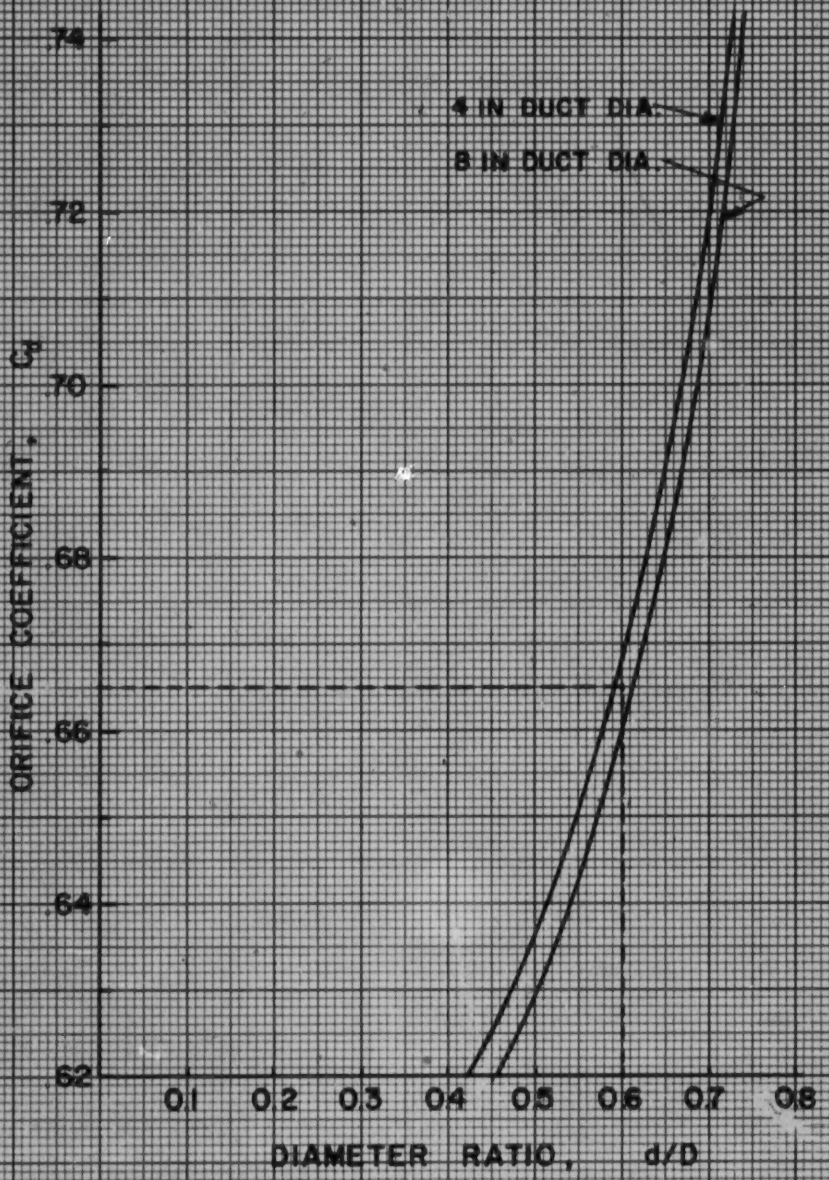
LENGTH OF DUCT BETWEEN FAN OUTLET AND UPSTREAM PRESSURE TAP, L = 45 IN

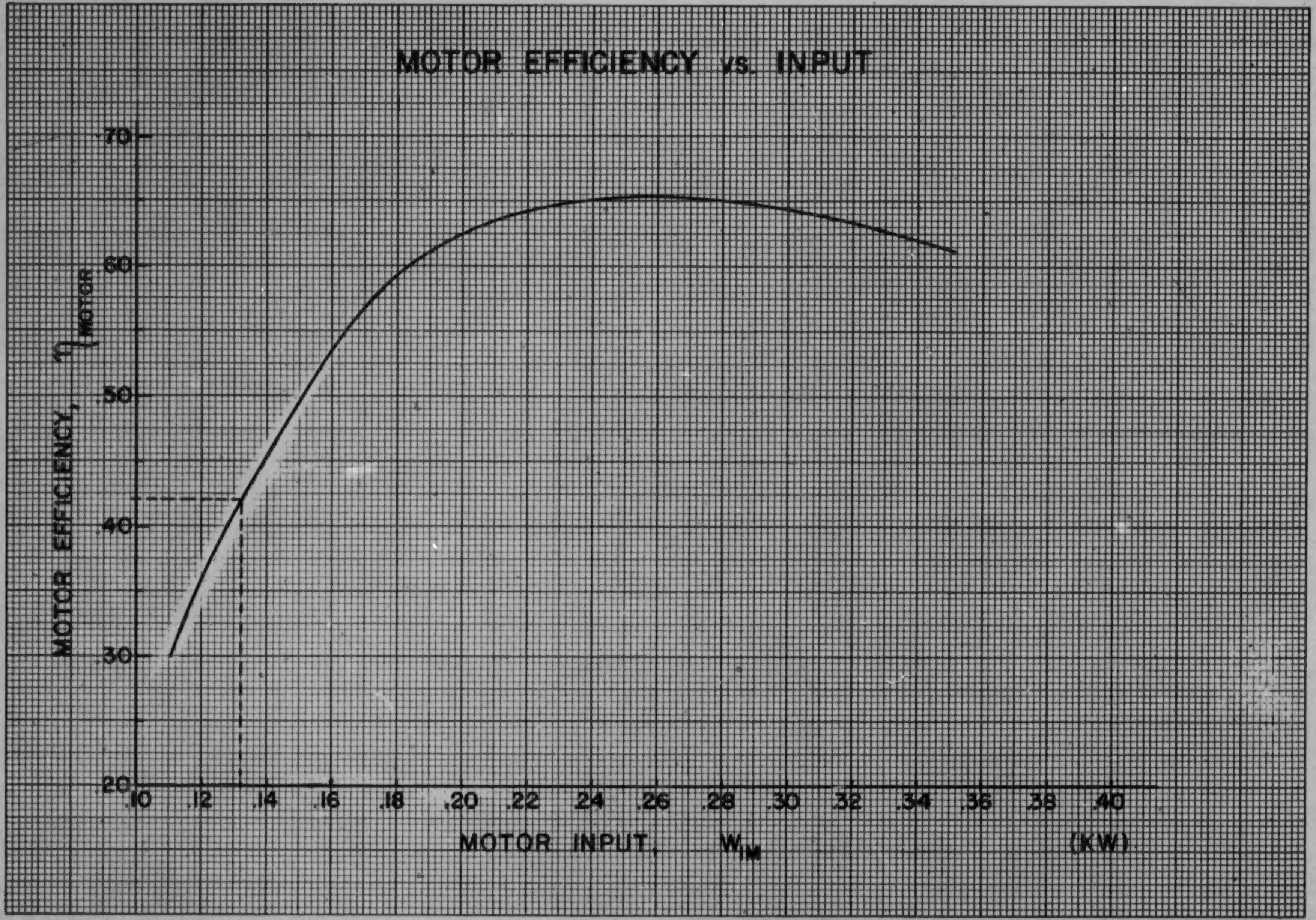
MANOMETER SCALE FACTORS: UPSTREAM PRESSURE TAP = 0.167

ACROSS ORIFICE = 0.162

222/a

ORIFICE COEFFICIENT
VS
DIAMETER RATIO




MOTOR EFFICIENCY vs. INPUT
MOTOR EFFICIENCY, η_{MOTOR}
70
60
50
40
30
20
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
MOTOR INPUT, W_{IM}
(KW)

SAMPLE CALCULATIONS

1. INPUT TO MOTOR (W_{IM})

$$W_{IM} = \frac{(\text{VOLTS})(\text{AMPS})}{1000}$$

$$= \frac{(89)(1.69)}{1000}$$

$$= 0.150 \text{ KW}$$

2. MOTOR EFFICIENCY (η_{MOTOR})

From manufacturer's performance curves

$$\eta_{MOTOR} = 50\%$$

3. MOTOR OUTPUT = FAN INPUT (W_{IF})

$$W_{IF} = (W_{IM})(\eta_{MOTOR})(1.341 \text{ HP/KW})$$

$$= (0.150 \text{ KW})(0.50)(1.341 \text{ HP/KW})$$

$$= 0.101 \text{ HP}$$

4. AIR VELOCITY IN DUCT (V)

$$V = 1096 \left(\frac{d}{D}\right)^2 C_d \sqrt{\frac{\Delta h}{\rho_A}}$$

$$\rho_A = \frac{P}{RT}$$

$$P = P_S + P_{BAROMETRIC}$$

$$P = \left[1.23 \text{ in. } H_2O + (30.0 \text{ in. Hg})\left(13.6 \frac{\text{in. } H_2O}{\text{in. Hg}}\right) \right] \cdot$$

$$(5.202) \frac{\text{lbf/ft}^2}{\text{in. } H_2O}$$

$$= 2130 \text{ lbf/ft}^2 \text{ ABSOLUTE}$$

$$\rho_A = \frac{P}{RT}$$

$$= \frac{2130 \text{ lbf/ft}^2}{\left(53.3 \frac{\text{ft-lbf}}{\text{lbm-}^\circ\text{R}}\right)(524^\circ \text{R})}$$

$$= 0.0737 \text{ lbm/ft}^3$$

$$V = (1096)\left(\frac{3.40}{5.75}\right)^2 (0.661) \sqrt{\frac{2.02}{0.0737}}$$

$$= 1325 \text{ ft./min.}$$

5. STATIC PRESSURE DROP (ΔP_s)

$$\Delta P_s = 0.02 \frac{L}{D} P_V$$

$$P_V = \left(\frac{d}{D}\right)^4 (Cd)^2 \Delta h$$

$$= \left(\frac{3.40}{5.75}\right)^4 (0.661)^2 (2.02)$$

$$= 0.108 \text{ in. } H_2O$$

$$\Delta P_s = (0.02)\left(\frac{45}{5.75}\right)(0.108)$$

$$= 0.02 \text{ in. } H_2O$$

6. STATIC PRESSURE AT FAN OUTLET (P_{SFO})

$$P_{SFO} = P_S + \Delta P_S$$

$$= 1.23 + 0.02 \text{ in. } H_2O$$

$$= 1.25 \text{ in. } H_2O$$

7. TOTAL PRESSURE IN DUCT (P_T)

$$P_T = P_S + P_V$$

$$= 1.23 + 0.108 \text{ in. } H_2O$$

$$= 1.34 \text{ in. } H_2O$$

8. VOLUME FLOW RATE (Q)

$$Q = VA$$

$$= (1325 \text{ ft/min.})\left[\pi/4\left(\frac{5.75}{12}\right)^2 \text{ft}^2\right]$$

$$= 239 \text{ ft}^3/\text{min.}$$

9. MASS FLOW RATE ($\dot{m}$)

$$\dot{m} = \rho_A Q$$

$$= (0.0737 \text{ lbm/ft}^3)(239 \text{ ft}^3/\text{min.})$$

$$= 17.6 \text{ lbm/min.}$$

10. STATIC FAN OUTLET PRESSURE (h_{AS})

$$h_{AS} = \frac{P_{SFO}}{\rho_A}$$

$$= \frac{1.25 \text{ in. } H_2O}{0.0737 \ \text{lbm}/\text{ft}^3{}_{AIR}} \left(5.202 \ \frac{\text{lbf}/\text{ft}^2}{\text{in. } H_2O}\right)$$

$$= 88.2 \text{ ft. OF AIR}$$

11. TOTAL FAN OUTLET PRESSURE (h_{AT})

$$h_{AT} = \frac{P_T}{\rho_A}$$

$$= \frac{1.34}{0.0737}(5.202)$$

$$= 94.5 \text{ ft. OF AIR}$$

12. STATIC AIR HORSEPOWER (HP_{AS})

$$HP_{AS} = \frac{\dot{m}\, g\, h_{AS}}{g_c \ 33000 \ \frac{\text{ft-lbf}/\text{min}}{HP}}$$

$$= \frac{(17.6 \ \text{lbm}/\text{min})(32.2 \ \text{ft}/\text{sec}^2)(88.2 \text{ ft})}{\left(32.2 \ \frac{\text{lbm-ft}}{\text{lbf-sec}^2}\right)\left(33000 \ \frac{\text{ft-lbf}/\text{min.}}{HP}\right)}$$

$$= 0.047 \text{ HP}$$

13. TOTAL AIR HORSEPOWER (HP_{AT})

$$HP_{AT} = \frac{\dot{m}\, g\, h_{AT}}{g_c\, 33{,}000}$$

$$= \frac{(17.6\ \text{lbm/min})(32.2\ \text{ft/sec}^2)(94.5\ \text{ft})}{\left(32.2\ \frac{\text{lbm-ft}}{\text{lbf-sec}^2}\right)\left(33{,}000\ \frac{\text{ft-lbf/min}}{\text{HP}}\right)}$$

$$= 0.050\ \text{HP}$$

14. STATIC FAN EFFICIENCY (η_{FS})

$$\eta_{FS} = \frac{HP_{AS}}{W_{IF}} \times 100\%$$

$$= \frac{0.047}{0.101} \times 100\%$$

$$= 47\%$$

15. TOTAL FAN EFFICIENCY (η_{FT})

$$\eta_{FT} = \frac{HP_{AT}}{W_{IF}} \times 100\%$$

$$= \frac{0.050}{0.101} \times 100\%$$

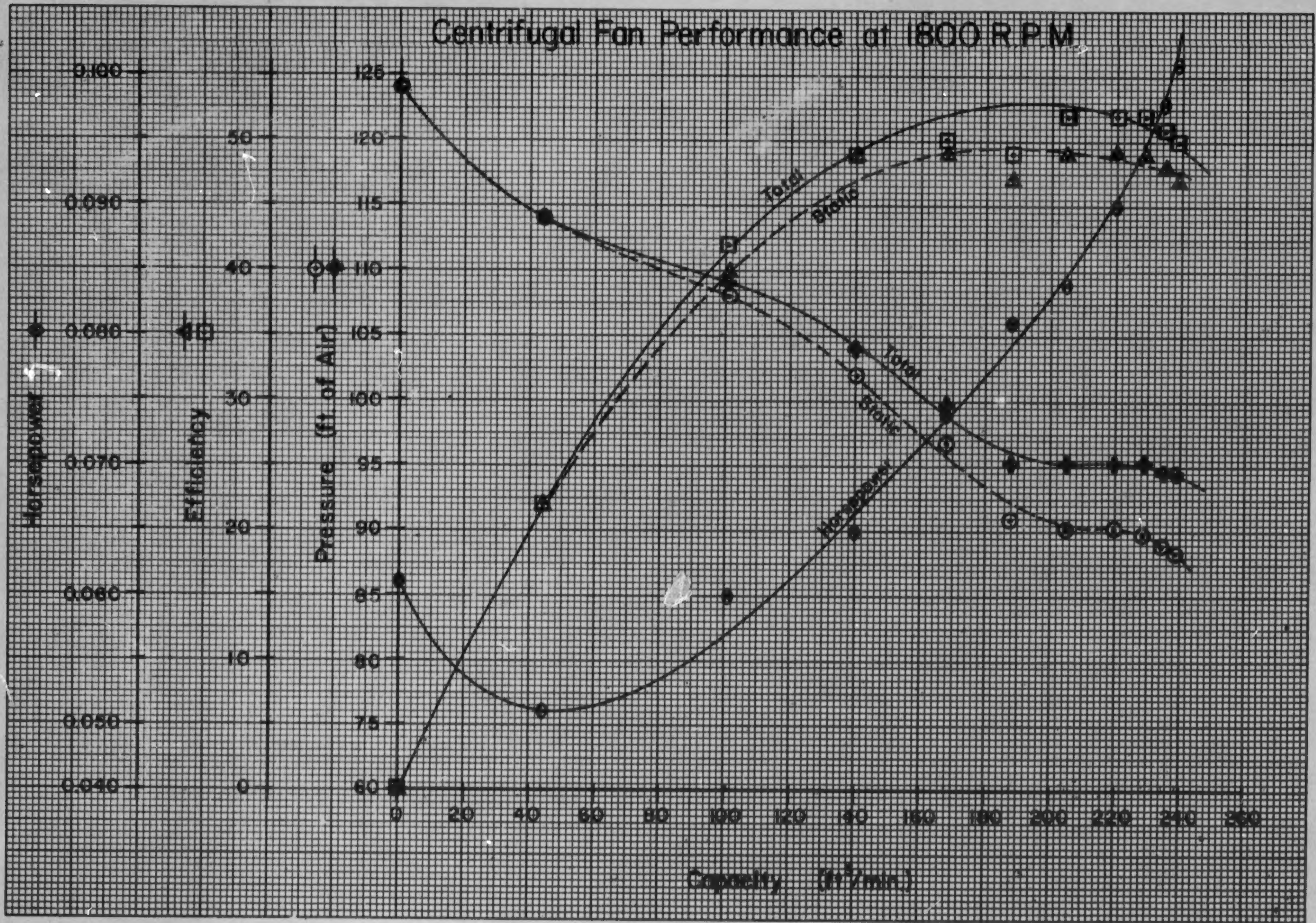
$$= 50\%$$

RESULTS

FAN SPEED = 1800 RPM

DUCT EXIT SETTING	MOTOR			AIR VELOCITY	STATIC PRESS. DROP	FAN OUTLET PRESSURES	
	INPUT W_{IM}	EFF η_{MOTOR}	OUTPUT W_{OM}	V	Δp_s	STATIC p_{sfo}	TOTAL p_t
	KW		HP	FT/MIN	"H_2O	"H_2O	"H_2O
OPEN	0.150	0.50	0.101	1325	0.02	1.25	1.34
0.9	0.149	0.49	0.098	1306	0.02	1.26	1.34
0.8	0.146	0.48	0.094	1269	0.02	1.27	1.35
0.7	0.143	0.47	0.090	1222	0.02	1.28	1.35
0.6	0.139	0.45	0.084	1138	0.01	1.28	1.35
0.5	0.137	0.44	0.081	1045	0.01	1.29	1.35
0.4	0.131	0.42	0.074	933	0.01	1.37	1.41
0.3	0.125	0.39	0.065	774	0.01	1.45	1.48
0.2	0.121	0.37	0.060	560	0.00	1.53	1.55
0.1	0.115	0.33	0.051	246	0.00	1.61	1.61
CLOSED	0.122	0.37	0.061	0	0.00	1.76	1.76

	AIR RATE OF FLOW		FAN OUTLET PRESSURES		FAN AIR HORSE POWER		FAN EFFICIENCIES	
	VOLUME Q	MASS $\dot{m}$	STATIC h_{AS}	TOTAL h_{AT}	STATIC HP_{AS}	TOTAL HP_{AT}	STATIC η_{FS}	TOTAL η_{FT}
	FT³/MIN	LBM/MIN	FT-AIR	FT-AIR	HP	HP	%	%
1.0	239	17.6	88.2	94.5	0.047	0.050	47	50
0.9	235	17.3	88.9	94.5	0.047	0.050	48	51
0.8	229	16.9	89.6	95.3	0.046	0.049	49	52
0.7	220	16.2	90.3	95.3	0.044	0.047	49	52
0.6	205	15.1	90.3	95.3	0.041	0.044	49	52
0.5	188	13.8	91.0	95.3	0.038	0.040	47	49
0.4	168	12.4	96.7	99.5	0.036	0.037	49	50
0.3	140	10.3	102.0	104.0	0.032	0.032	49	49
0.2	101	7.43	108.0	109.0	0.024	0.025	40	42
0.1	44	3.24	114.0	114.0	0.011	0.011	22	22
0	0	0.00	124.0	124.0	0.000	0.000	0	0


Centrifugal Fan Performance at 1800 R.P.M.
Horsepower
0.100
0.090
0.080
0.070
0.060
0.050
0.040
Efficiency
50
40
30
20
10
0
Pressure (ft. of Air)
125
120
115
110
105
100
95
90
85
80
75
60
Total
Static
Total
Static
Horsepower
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Capacity (ft³/min.)

```
      REAL MDOT(11)
      DIMENSION H(11),PS(11),V(11),A(11),TEMP(11),WIM(11),E(11),WOM(11),
     XVEL(11),DPS(11),PSFO(11),PT(11),Q(11),HAS(11),HAT(11),
     XHPAS(11),HPAT(11),ES(11),ET(11),PSA(11),RHO(11),PV 11
C     NSF 9226 EXPERIMENT ON FAN TESTING AND PERFORMANCE
C                INFORMATION
C     H=CORRECTED MANOMETER READING ACROSS ORIFICE IN INCHES OF WATER
C     PS=CORRECTED UPSTREAM STATIC PRESSURE IN INCHES OF WATER
C     V=VOLTAGE IN VOLTS
C     A=CURRENT IN AMPERES
C     TEMP=AIR TEMPERATURE IN DEGREES FAHRENHEIT
C     WIM=MOTOR INPUT IN KW
C     E=EFFICIENCY
C     WOM=MOTOR OUTPUT IN KW
C     VEL=VELOCITY IN FT/MIN
C     DPS=STATIC PRESSURE DROP IN INCHES OF WATER
C     PSFO=FAN OUTLET STATIC PRESSURE IN INCHES OF WATER
C     PT=FAN OUTLET TOTAL PRESSURE IN INCHES OF WATER
C     Q=AIR-VOLUME RATE OF FLOW IN CUBIC FT/MIN
C     MDOT=AIR-MASS RATE OF FLOW IN LB/MIN
C     HAS=FAN OUTLET STATIC PRESSURE IN FT OF AIR
C     HAT=FAN OUTLET TOTAL PRESSURE IN FT OF AIR
C     HPAS=STATIC FAN AIR HORSEPOWER
C     HPAT=TOTAL FAN AIR HORSEPOWER
C     ES=STATIC FAN EFFICIENCY
C     PSA=ABSOLUTE STATIC PRESS(LB/SQ.FT)
C     ET=TOTAL FAN EFFICIENCY
C     DO=ORIFICE DIAMETER IN INCHES
C     DD=DUCT DIAMETER IN INCHES
C     CD=ORIFICE COEFFICIENT
C     FS=FAN SPEED IN RPM
C                PRINT DATA
      WRITE 3,108
  108 FORMAT(1H1,25X,'INPUT DATA'/)
      WRITE(3,101)
  101 FORMAT(12X,'MOTOR INPUT',9X,'AIR',3X,'CORRECTED MAN RDG',5X,
     X'MOTOR'/10X,
     1'VOLTS',6X,'AMPS',6X,'TEMP',3X,'DELTA H',4X,'STATIC',7X,'EFF'/)
      READ(2,110)(V(M),A(M),TEMP(M),H(M),PS(M),E(M),M=1,11)
  110 FORMAT(6F10.2)
      WRITE(3,102)(V(M),A(M),TEMP(M),H(M),PS(M),E(M),M=1,11)
  102 FORMAT(9X,F6.1,4X,F6.2,4X,F6.1,3F10.2)
C                CALCULATIONS
      DO=3.4
      DD=5.75
      CD=.661
C     BAROMETRIC PRESSURE=30.0 INCHES OF HG.
C     FAN SPFED=1800 RPM
C     LENGTH OF DUCT BETWEEN FAN OUTLET AND UPSTREAM PRESS.TAP=45 INCHES
      D=45.
      DO 120 J=1,11
      WIM(J)=V(J)*A(J)/1000.
C     MOTOR EFFICIENCY FROM MANUFACTURERS PERFORMANCE CURVFS=50 PERCENT
      WOM(J)=WIM(J)*E(J)*1.341
C     CALCULATE ABSOLUTE STATIC PRESSURE IN LB/SQ. FT.
      PSA(J)=(PS(J)+30.*13.6)*5.202
      PSA J   PS J &30.0*13.6 *5.202
C     CALCULATING DENSITY(RHO)LB/CUBIC FT.
      RHO(J)=PSA(J)/(53.3*(TEMP(J)+460.))
      VEL(J)=1096.*(DO/DD)**2.0*CD*SQRT(H(J)/RHO(J))
C     CALCULATING VELOCITY PRESSURE(PV)IN INCHES OF WATER
      PV(J)=(DO/DD)**4.0*(CD)**2.0*H(J)
      DPS(J)=.02*(D/DD)*PV(J)
      PSFO(J)=PS(J)+DPS(J)
      PT(J)=PSFO(J)+PV(J)
      Q(J)=VEL(J)*.785*(5.75/12.)**2.0
      MDOT(J)=RHO(J)*Q(J)
      HAS(J)=PSFO(J)*5.202/RHO(J)
      HAT(J)=PT(J)*5.202/RHO(J)
      HPAS(J)=(MDOT(J)*32.2*HAS(J))/(32.2*33000.)
      HPAT(J)=(MDOT(J)*32.2*HAT(J))/(32.2*33000.)
      ES(J)=(HPAS(J)/WOM(J))*100.
      ET(J)=(HPAT(J)/WOM(J))*100.
  120 CONTINUE
C                PRINT RESULTS
      WRITE(3,103)
  103 FORMAT(1H1,35X,'RESULTS'//,14X,'MOTOR PARAMETERS',12X,'AIR',4X,
     1'STATIC',4X,'FAN OUTLET PRESS'/10X,'INPUT',7X,'EFF',4X,'OUTPUT'
     2,2X,'VELOCITY',3X,'DELTA P',4X,'STATIC',5X,'TOTAL'/11X,'(KW)',
     35X,'(PCT)',6X,'(HP)',2X,'(FT/MIN)',3(2X,'(IN-H2O)')/)
      WRITE(3,104)(WIM(K),E(K),WOM(K),VEL(K),DPS(K),PSFO(K),PT(K),K=1,11
     X)
  104 FORMAT(5X,3F10.3,4X,F6.1,3F10.3)
      WRITE(3,105)
  105 FORMAT(////9X,'AIR RATE OF FLOW',4X,'FAN OUTLET PRESS',8X,
     1'FAN AIR HP',6X,'FAN EFFICIENCIES'/9X,'VOLUME',6X,'MASS',4X,
     23('STATIC',5X,'TOTAL',4X)/6X,'(FT3/MIN)',1X,'(LBM/MIN)',2(2X,
     3'(FT-AIR)'),2(6X,'(HP)'),2(5X,'(PCT)')/)
      WRITE(3,106)(Q(N),MDOT(N),HAS(N),HAT(N),HPAS(N),HPAT(N),ES(N),ET(N
     X),N=1,11)
  106 FORMAT(5X,4F10.1,2F10.3,2F10.1)
      CALL EXIT
      END
```

```
                  INPUT DATA

   MOTOR INPUT            AIR    CORRECTED MAN RDG       MOTOR
 VOLTS       AMPS        TEMP    DELTA H    STATIC        EFF

  89.0       1.69        82.0       2.02      1.23       0.50
  89.0       1.67        82.0       1.95      1.24       0.49
  89.0       1.64        82.0       1.84      1.25       0.48
  88.0       1.63        82.0       1.71      1.26       0.47
  87.0       1.60        82.0       1.49      1.27       0.45
  87.0       1.58        82.0       1.26      1.28       0.44
  85.0       1.54        83.0       1.01      1.36       0.42
  83.0       1.50        83.0       0.69      1.44       0.39
  82.0       1.48        83.0       0.36      1.53       0.37
  80.0       1.44        83.0       0.07      1.61       0.33
  82.0       1.49        83.0       0.00      1.76       0.37
```

```
                              RESULTS

     MOTOR PARAMETERS              AIR       STATIC     FAN OUTLET PRESS
  INPUT       EFF      OUTPUT    VELOCITY    DELTA P     STATIC     TOTAL
  (KW)       (PCT)      (HP)    (FT/MIN)    (IN-H2O)   (IN-H2O)   (IN-H2O)

  0.150      0.500      0.100     1326.1      0.016      1.246      1.354
  0.148      0.490      0.097     1302.9      0.016      1.256      1.360
  0.145      0.480      0.093     1265.6      0.015      1.265      1.363
  0.143      0.470      0.090     1220.1      0.014      1.274      1.365
  0.139      0.450      0.084     1138.9      0.012      1.282      1.362
  0.137      0.440      0.081     1047.3      0.010      1.290      1.357
  0.130      0.420      0.073      938.4      0.008      1.368      1.422
  0.124      0.390      0.065      775.6      0.005      1.445      1.482
  0.121      0.370      0.060      560.1      0.003      1.533      1.552
  0.115      0.330      0.050      246.9      0.000      1.610      1.614
  0.122      0.370      0.060        0.0      0.000      1.760      1.760


   AIR RATE OF FLOW      FAN OUTLET PRESS           FAN AIR HP         FAN EFFICIENCIES
   VOLUME       MASS     STATIC      TOTAL       STATIC      TOTAL       STATIC      TOTAL
 (FT3/MIN) (LBM/MIN)   (FT-AIR)   (FT-AIR)        (HP)       (HP)        (PCT)      (PCT)

    239.0       17.6       88.0       95.6       0.046      0.051         46.5       50.6
    234.8       17.3       88.6       96.0       0.046      0.050         47.6       51.5
    229.1       16.8       89.3       96.2       0.045      0.049         48.4       52.1
    219.9       16.2       89.9       96.3       0.044      0.047         48.8       52.3
    205.2       15.1       90.5       96.1       0.041      0.044         49.4       52.4
    189.7       13.9       91.0       95.8       0.038      0.040         47.3       49.9
    169.1       12.4       96.7      100.5       0.036      0.037         49.4       51.4
    139.7       10.2      102.1      104.8       0.031      0.032         48.9       50.1
    100.9        7.4      108.3      109.6       0.024      0.024         40.5       41.0
     44.5        3.2      113.7      114.0       0.011      0.011         22.1       22.2
      0.0        0.0      124.3      124.3       0.000      0.000          0.0        0.0
```

EXPERIMENT NO. 16

FAN LAWS

A ORIFICE
B PITOT TUBE

Data Sheet

(Orifice)

Fan Speed rpm	Manometer Readings ("H_2O)		Motor Input			Motor Eff. (%) *
	Upstream Static	Static Diff.	Volts	Amps	KW	
1850	8-1/8	13-1/2	95	1.70	0.162	54.2
1800	8	13-3/8	90	1.68	0.151	50.0
1750	7-5/8	12-3/8	89	1.62	0.144	47.0
1700	7-1/16	11-3/4	84	1.59	0.134	42.5
1650	6-1/2	10-15/16	80	1.52	0.121	36.5
1600	6-5/16	9-3/16	78	1.50	0.117	34.7

Orifice Diameter 3.40 in.

Duct Diameter 5.75 in.

Orifice Coefficient 0.66

Air Temperature 94 °F

Barometric Pressure 29.92 in. Hg

* from efficiency curve

Manometer No. 1

Initial Reading 0.0

Correction Factor 0.167

Manometer No. 2

Initial Reading 1/8 in.

Correction Factor 0.162

SAMPLE CALCULATIONS
(ORIFICE)

1. AIR DENSITY ($lbm/ft.^3$)

$$144\,Pv = WRT$$

$$\rho_{AIR} = \frac{W}{v} = \frac{144\,P}{RT}$$

$$= \frac{(144\ in^2/ft^2)(29.92\ in.Hg)(0.491\ lbf/in^2\text{-}in.Hg)}{(53.3\ \frac{ft.\text{-}lbf}{lbm\text{-}°R})(94 + 460\ °R)}$$

$$= 0.0716\ lbm/ft^3$$

2. DUCT AREA ($ft.^2$)

$$A = \frac{\pi}{4} d^2$$

$$= \left(\frac{\pi}{4}\right)\left(\frac{5.75}{12}\right)^2$$

$$= 0.180\ ft.^2$$

3. STATIC DIFFERENCE (in. H_2O)

$$\Delta h = (\text{Manometer Reading} - \text{Zero Reading})(\text{Correction Factor})$$

$$= (13.5 - 0.125)(0.162)\ in.\ H_2O$$

$$= 2.17\ in.\ H_2O$$

4. MOTOR INPUT (KW)

$$KW = \frac{(\text{Volts})(\text{Amps})}{1000} = \frac{(95)(1.70)}{1000}$$

$$KW = 0.162$$

5. VELOCITY (ft./min.)

$$V = 1096 \frac{d^2}{D^2} Cd \sqrt{\frac{\Delta h}{\rho_{AIR}}}$$

$$= C\sqrt{\Delta h} \quad \text{where: } C = 1096 \frac{d^2}{D^2} Cd \sqrt{\frac{1}{\rho_{AIR}}}$$

$$= 1096 \frac{(3.40)^2}{(5.75)^2} (0.66) \sqrt{\frac{1}{0.0716}}$$

$$= 945.92$$

$$V = 945.92 \sqrt{2.17}$$

$$= 1390 \text{ ft./min.}$$

6. CAPACITY (ft.³/min.)

$$Q = AV$$

$$= (0.180 \text{ ft.}^2)(1390 \text{ ft./min.})$$

$$= 250.2 \text{ ft}^3\text{/min.}$$

7. VELOCITY HEAD (in. H_2O)

$$H_V = \left(\frac{d}{D}\right)^4 Cd^2 \Delta h$$

$$= \left(\frac{3.40}{5.75}\right)^4 (0.66)^2 (2.17)$$

$$= 0.116 \text{ in. } H_2O$$

8. STATIC HEAD (in. H_2O)

H_S = (Manometer Reading)(Correction Factor)

= (8.125)(0.167)

= 1.357 in. H_2O

9. TOTAL HEAD (in. H_2O)

$H_T = H_S + H_V$

= 1.357 + 0.116 in. H_2O

= 1.473 in. H_2O

10. INPUT TO FAN (HP)

$HP = (Kw)(\eta_{MOTOR})(1.34\ ^{HP}/_{Kw})$

$= (0.162\ Kw)(0.542)(1.34\ ^{HP}/_{Kw})$

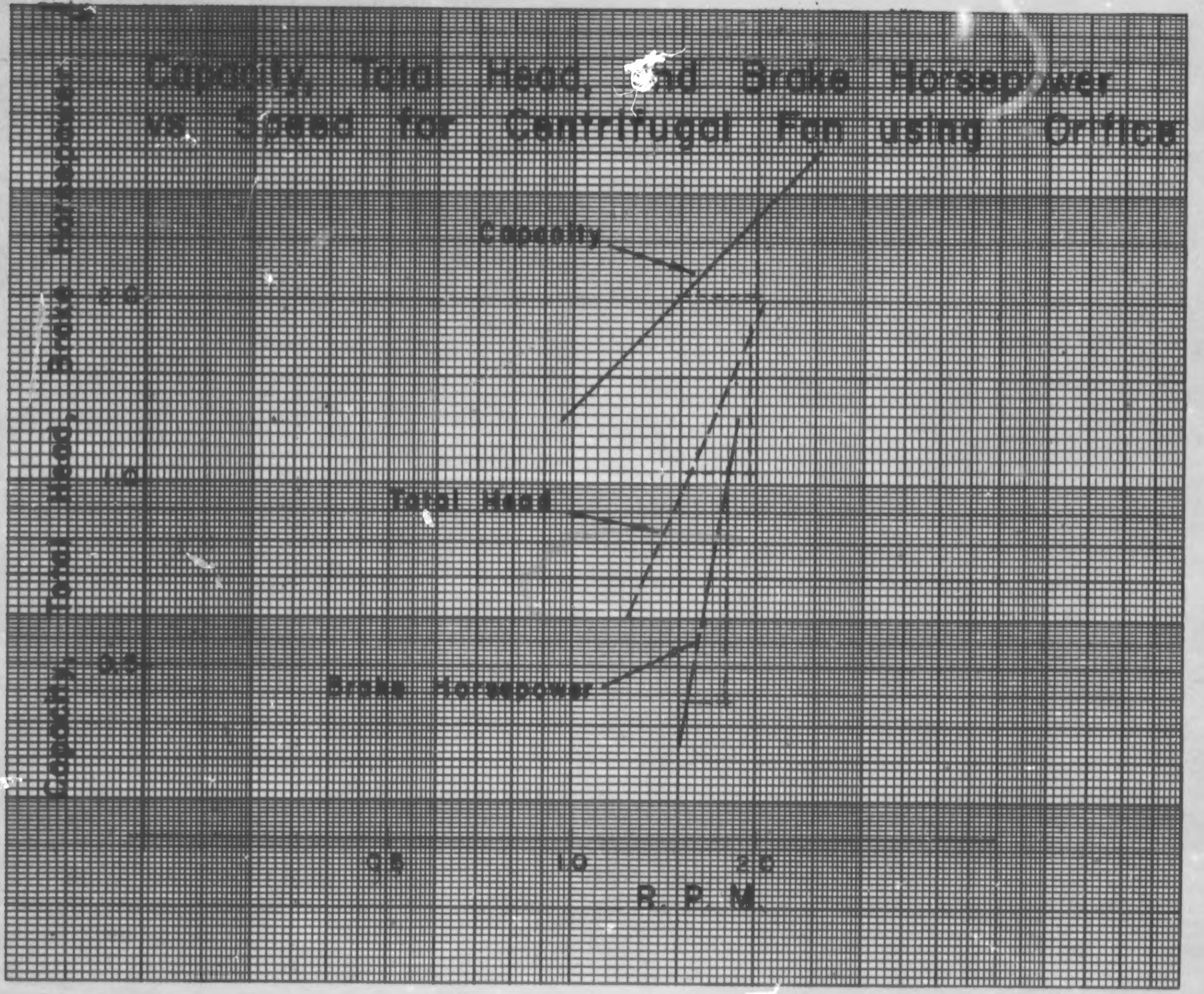
HP = 0.118

Results Sheet

(Orifice)

Fan Speed (rpm)	Static Diff. (in. of H_2O)	Velocity (ft/min)	Capacity (cu ft/min)	Velocity Head (in. of H_2O)	Static Head (in. of H_2O)	Total Head (in. of H_2O)	Input to Fan (Horsepower)
1850	2.17	1390	250.2	0.116	1.357	1.473	0.118
1800	2.14	1381	248.6	0.114	1.336	1.450	0.101
1750	1.98	1334	240.1	0.105	1.273	1.378	0.091
1700	1.88	1296	233.3	0.100	1.179	1.279	0.076
1650	1.75	1253	225.5	0.0931	1.086	1.179	0.059
1600	1.49	1154	207.7	0.0793	1.054	1.133	0.054

Duct Area 0.180 ft.^{2} Air Density 0.0716 lbm/ft.^{3}


Capacity, Total Head, and Brake Horsepower vs. Speed for Centrifugal Fan using Orifice

DETERMINATION OF SLOPES

1. Capacity vs. R.P.M.

$$m = \frac{\ln 2.75/2.05}{\ln 2.00/1.50} = \frac{\ln 1.34}{\ln 1.33} = 1.026$$

2. Total Head vs. R.P.M.

$$m = \frac{\ln 1.75/1.05}{\ln 1.95/1.55} = \frac{\ln 1.67}{\ln 1.26} = 2.19$$

3. Brake Horsepower vs. R.P.M.

$$m = \frac{\ln 1.00/0.44}{\ln 1.80/1.55} = \frac{\ln 2.27}{\ln 1.16} = 5.80$$

```
      WRITE(3,2000)
 2000 FORMAT(1H1,33X,'FAN LAWS (ORIFICE)'/)
      WRITE(3,2001)
 2001 FORMAT(11X,'FAN',5X,'STATIC',2X,'VELOCITY',2X,'CAPACITY',2X,
     1'VELOCITY',4X,'STATIC',5X,'TOTAL',5X,'INPUT'/10X,'SPEED',6X,
     2'DIFF',5X,'(FPM)',5X,'(CFM)',6X,'HEAD',6X,'HEAD',6X,'HEAD',4X,
     3'TO FAN'/10X,'(RPM)',6X,'(IN)',26X,3('(IN)',6X),'(HP)'/)
C     CALCULATE DUCT AREA
      A=.7854*(5.75/12)**2
C     CALCULATE AIR DENSITY
      RHO 144.*14.696/ 53.3*554
C     INITIAL MAN RDG
      C1=0.125
C     MANOM. NO2 CURR. FACT.
      C2=0.162
C     MANOM NO1 CURR FACT
      C3=0.167
C     ORIFICE DIAMETER
      C4=3.40
C     DUCT DIAMETER
      C5=5.75
C     ORIFICE COEFF.
      CD=0.66
      C6= 1096*((3.40/5.75)**2)*CD*((1/RHO)**0.5)
      C7   3.40/5.75 **4. *CD**2.
      DO2010 I=1,6
      READ(2,2002)FS,US,SD,VOLTS,AMPS,ETTA
 2002 FORMAT(6F10.0)
C     CALCULATE STATIC DIFF.(IN WATER)
      DELH=(SD-C1)*C2
C     CALCULATE MOTOR INPUT (KW)
      AKW=VOLTS*AMPS/1000.
C     CALCULATE VELOCITY (FT/MIN)
      VEL=C6*DELH**0.5
C     CALCULATE CAPACITY (CUBIC FEET/MIN)
      CAP=A*VEL
C     CALCULATE VELOCITY HEAD(IN WATER)
      VH =C7*DELH
C     CALCULATE STATIC HEAD (IN WATER)
      SH=US*C3
C     CALCULATE TOTAL HEAD (IN WATER)
      TH=SH+VH
C     CALCULATE INPUT TO FAN (HP)
      FHP=AKW*ETTA*1.34
 2010 WRITE(3,2011)FS,DELH,VEL,CAP,VH,SH,TH,FHP
 2011 FORMAT(9X,F6.1,4X,F6.2,4X,F6.1,4X,F6.2,4(4X,F6.3))
      WRITE(3,2012)A,RHO
 2012 FORMAT(/10X,'DUCT AREA= ',F6.3,' SQ FT',5X,'AIR DENSITY= ',
     1F6.4,' LBM/FT3')
      CALL EXIT
      END
```

```
                                   FAN LAWS (ORIFICE)

  FAN       STATIC   VELOCITY   CAPACITY   VELOCITY      STATIC       TOTAL       INPUT
 SPEED       DIFF      (FPM)      (CFM)        HEAD        HEAD        HEAD      TO FAN
 (RPM)       (IN)                              (IN)        (IN)        (IN)        (HP)

1850.0       2.16     1390.6     250.77       0.115       1.356       1.472       0.117
1800.0       2.14     1384.1     249.59       0.114       1.336       1.450       0.101
1750.0       1.98     1330.8     239.99       0.105       1.273       1.379       0.090
1700.0       1.88     1296.4     233.79       0.100       1.179       1.279       0.076
1650.0       1.75     1250.3     225.47       0.093       1.085       1.178       0.059
1600.0       1.46     1144.7     206.42       0.078       1.054       1.132       0.054

 DUCT AREA=  0.180 SQ FT       AIR DENSITY= 0.0716 LBM/FT3
```

Data Sheet

(Pitot - Tube)

Fan Speed rpm	Manometer Readings (H_2O)		Motor Input			Motor Eff. (%) *
	Total	Static	Volts	Amps	KW	
1500	4-15/16	5/16	95	2.21	0.210	63.5
1450	4-3/4	5/16	92	2.19	0.200	62.5
1400	4-1/2	5/16	89	2.12	0.189	61.0
1350	4-1/4	5/16	81	2.00	0.162	54.2
1250	3-11/16	5/16	75	1.85	0.139	45.2
1200	3-3/8	5/16	70	1.80	0.126	39.5

Air Temperature 94°F

Barometric Pressure 29.92 in. Hg

Manometer No. 1

Initial Reading 0.00

Correction Factor 0.167

Manometer No. 2

Initial Reading 1/4 in.

Correction Factor 0.162

* from efficiency curve

SAMPLE CALCULATIONS
(PITOT - TUBE)

1. AIR DENSITY $(\mathrm{lbm/ft.^3})$

$$144\,P v = W R T$$

$$\rho_{AIR} = \frac{W}{v} = \frac{144\,P}{RT}$$

$$= \frac{(144\ \mathrm{in^2/ft.^2})(29.92\ \mathrm{in.\,Hg})(0.491\ \mathrm{lbf/in.^2\text{-}in.\,Hg})}{\left(53.3\ \frac{\mathrm{ft.\text{-}lbf}}{\mathrm{lbm\text{-}^\circ R}}\right)(94+460\ ^\circ\mathrm{R})}$$

$$= 0.0714\ \mathrm{lbm/ft^3}$$

2. WATER DENSITY $(\mathrm{lbm/ft.^3})$

$$\rho_{H_2O} = \frac{1}{v} \qquad v\ @\ 94^\circ\mathrm{F} = 0.01611\ \mathrm{ft.^3/lbm}$$

$$= \frac{1}{0.01611\ \mathrm{ft.^3/lbm}}$$

$$= 62.07\ \mathrm{lbm/ft.^3}$$

3. DUCT AREA $(\mathrm{ft.^2})$

$$A = \frac{\pi}{4} d^2$$

$$= \frac{\pi}{4}\left(\frac{5.75}{12}\right)^2$$

$$= 0.180\ \mathrm{ft.^2}$$

4. MOTOR INPUT (KW)

$$KW = \frac{(\text{Volts})(\text{Amps})}{1000}$$

$$= \frac{(95)(2.21)}{1000}$$

$$KW = 0.210$$

5. TOTAL HEAD (in. H_2O)

$$H_T = (\text{Manometer Reading})(\text{Correction Factor})$$

$$= (4.94 \text{ in. } H_2O)(0.167)$$

$$= 0.825 \text{ in. } H_2O$$

6. STATIC HEAD (in. H_2O)

$$H_S = (\text{Manometer Reading})(\text{Correction Factor})$$

$$= (5/16 - 1/4 \text{ in. } H_2O)(0.162)$$

$$= 0.010 \text{ in. } H_2O$$

7. VELOCITY HEAD (in. H_2O)

$$H_V = H_T - H_S$$

$$= 0.825 - 0.010 \text{ in. } H_2O$$

$$= 0.815 \text{ in. } H_2O$$

8. TOTAL HEAD (ft. of AIR)

$$H_T = (0.825 \text{ in. } H_2O)\left(\frac{1}{12} \text{ ft/in.}\right)\left(\frac{62.07 \text{ lbm/ft}^3\text{-}H_2O}{0.0714 \text{ lbm/ft}^3\text{-AIR}}\right)$$

$$= 59.8 \text{ ft. of AIR}$$

9. VELOCITY (ft./min.)

$$V = \sqrt{\frac{(2g)(H_V)(\rho_{H_2O})}{(12)(\rho_{AIR})}} \text{ ft./sec.}$$

$$= \sqrt{\frac{(2g)(\rho_{H_2O})}{(12)(\rho_{AIR})}} \times \sqrt{H_V} \text{ ft./sec.}$$

$$= (68.3\sqrt{H_V} \text{ ft./sec.})(60 \text{ sec./min.})$$

$$= 4097\sqrt{0.815} \text{ ft./min.}$$

$$= 3700 \text{ ft./min.}$$

10. CAPACITY (ft.³/min.)

$$Q = AV$$

$$= (0.180 \text{ ft.}^2)(3700 \text{ ft./min.})$$

$$= 666 \text{ ft.}^3\text{/min.}$$

11. INPUT TO FAN (HP)

$$HP = (KW)(\eta_{MOTOR})(1.34 \text{ HP/KW})$$

$$= (0.210)(0.635)(1.34)$$

$$HP = 0.178$$

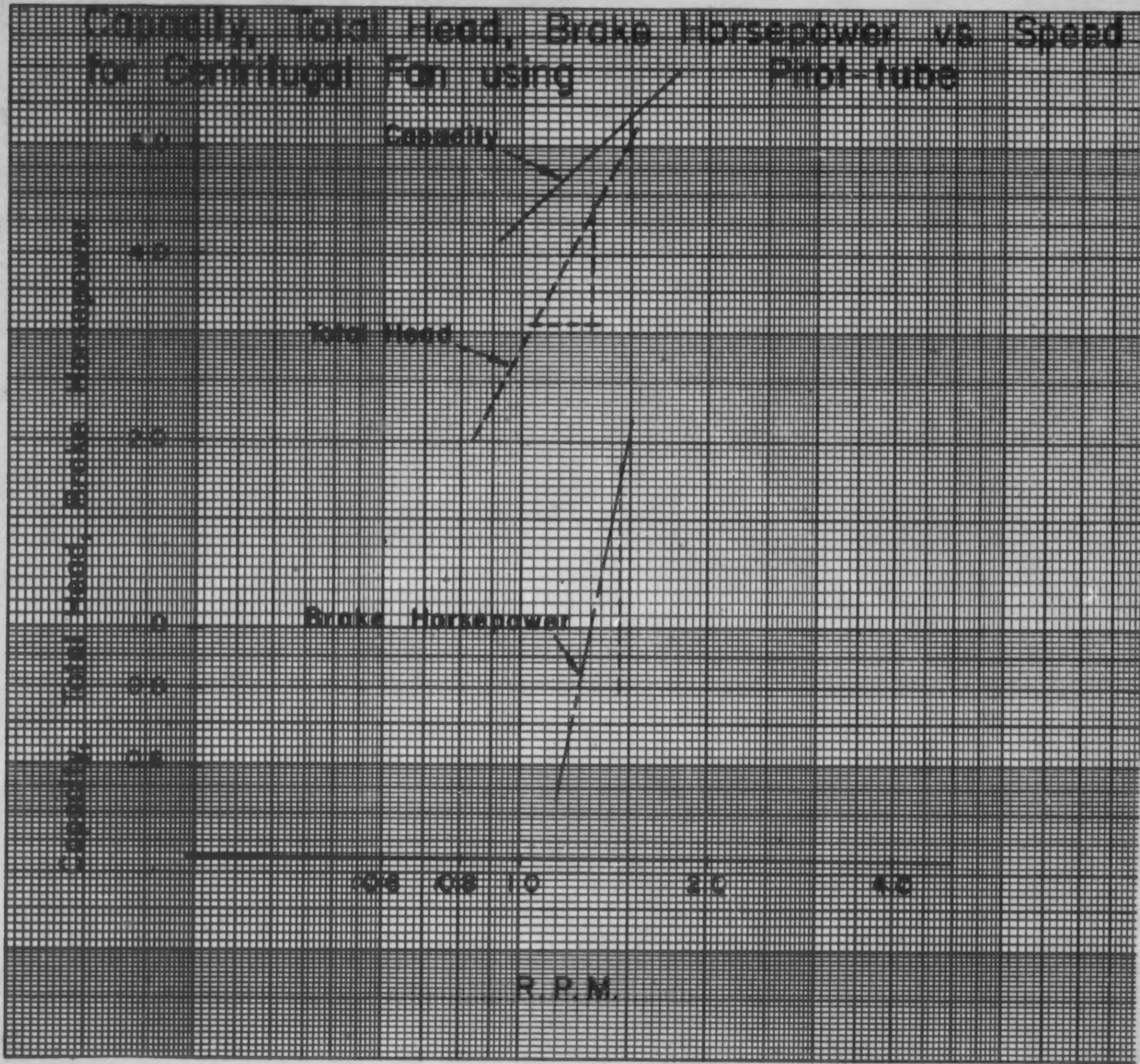
Results Sheet

(Pitot - Tube)

Fan Speed RPM	Corrected Manometer Readings ("H_2O)			Velocity (fpm)	Capacity (cfm)	Total Head (ft of Air)	Input to Fan (HP)
	Total	Static	Velocity				
1500	0.825	0.010	0.815	3700	666	59.8	0.178
1450	0.793	0.010	0.783	3630	653	57.4	0.168
1400	0.752	0.010	0.742	3530	635	54.4	0.152
1350	0.710	0.010	0.700	3430	617	51.4	0.118
1250	0.616	0.010	0.606	3190	574	44.6	0.084
1200	0.564	0.010	0.554	3050	549	40.8	0.067

Duct Area 0.180 ft^2.

Air Density 0.0714 lbm/ft^3.



DETERMINATION OF SLOPES

1. Capacity vs. R.P.M.

$$m = \frac{\ln 6.70/5.00}{\ln 1.50/1.07} = \frac{\ln 1.34}{\ln 1.40} = 0.87$$

2. Total Head vs. R.P.M.

$$m = \frac{\ln 5.40/3.10}{\ln 1.40/1.05} = \frac{\ln 1.74}{\ln 1.33} = 1.94$$

3. Brake Horsepower vs. R.P.M.

$$m = \frac{\ln 1.70/0.80}{\ln 1.45/1.25} = \frac{\ln 2.125}{\ln 1.16} = 5.09$$

```
C     FS FAN SPEED RPM
C     TH TOTAL MANOMETER PRESSURE INCHES OF WATER
C     SH STATIC MANOMETER PRESSURE INCHES OF WATER
C     ETTA MOTOR EFFICIENCY PERCENT
      WRITE(3,3002)
 3002 FORMAT(1H1,31X,'FAN LAWS (PITOT-TUBE)'/)
      WRITE(3,3000)
 3000 FORMAT(11X,'FAN',7X,'CORRECTED MANOMETER RDGS',2X,'VELOCITY',
     12X,'CAPACITY',5X,'TOTAL',6X,'FAN'/10X,'SPEED',12X,'(INCH',
     2'ES H2O)',11X,'(FPM)',5X,'(CFM)'6X,'HEAD',5X,'INPUT'/
     310X,'(RPM)',5X,'TOTAL',4X,'STATIC',2X,'VELOCITY',26X,
     4'(FT)',6X,'(HP)',//)
C     CALCULATE AIR DENSITY
      ROAIR=(144.*29.92*0.491)/(53.3*554.)
C     CALCULATE WATER DENSITY
      ROWAT=1/.01611
C     CALCULATE DUCT AREA
      AREA=.7854*((5.75/12)**2)
C     MAN. CORRECTION FACTORS
      C1=0.167
      C2=0.162
      C3=0.250
      DO3010 I=1,6
      READ(2,3001)FS,TH,SH,VOLT,AMP,ETTA
 3001 FORMAT(6F10.0)
      AKW=VOLT*AMP/1000.
C     CALCULATE TOTAL HEAD(IN WATER)
      HTW=TH*C1
C     CALCULATE STATIC HEAD(IN WATER)
      HS=(SH-.250)*C2
C     CALCULATE VELOCITY HEAD (IN WATER)
      HV HTW-HS
C     CALCULATE TOTAL HEAD (FEET AIR)
      HTA  HTW*ROWAT / 12.*ROAIR
C     CALCULATE VELOCITY
      VEL=SQRT((64.4*ROWAT)/(12.*ROAIR))*HV**0.5*60
      CAP=AREA*VEL
      FANIN=AKW*ETTA*1.34
 3010 WRITE(3,3011)FS,HTW,HS,HV,VEL,CAP,HTA,FANIN
 3011 FORMAT(9X,F6.0,3(4X,F6.3),3(4X,F6.1),4X,F6.3)
      WRITE(3,3012)AREA,ROAIR
 3012 FORMAT(/10X,'DUCT AREA=',F6.3,' SQFT',5X,'AIR DENSITY=',F7.4,' LBM
     6/FT3')
      CALL EXIT
      END
```

EXPERIMENT NO. 17

ENGINE TESTING

A - ENGINE EFFICIENCY
B - IGNITION TIMING
C - AIR-FUEL RATIO
D - ENGINE PERFORMANCE USING DIFFERENT FUELS
E - COMPRESSION RATIO

Data Sheet

RPM	Torque (in-lb)	Manifold Pressure (psig)	Cylinder Pressure (psig)	Fuel Flow (mm)
3300	5.0	3.8	49	10.6
3000	6.8	3.5	74	9.8
2700	7.8	3.0	59	9.1
2400	8.2	2.3	59	8.6
2100	9.2	1.4	67	8.2
1800	9.2	2.3	56	7.8
1500	9.8	1.4	70	7.2
1200	9.0	0.6	76	6.5
1000	8.2	0.0	76	5.9
750	6.1	0.0	78	5.1

Type of Fuel Alcohol

Heating Value of Fuel 10,000 Btu/lb

SAMPLE CALCULATIONS

1. HORSEPOWER (HP)

$$HP = \frac{T\ N}{63{,}000}$$

$$= \frac{(5.0 \text{ in.-lb})(3300 \text{ RPM})}{63{,}000 \ \frac{\text{in.-lb}}{\text{min.}}}$$

$$= 0.262$$

2. FUEL RATE ($^{\text{lbm}}/_{\text{min.}}$)

$$\dot{m}_f = \frac{\text{gm/min. (From Chart)}}{\text{gm/lbm}}$$

$$= \frac{7.7}{454} \text{ lbm/min.}$$

$$= 0.017 \ ^{\text{lbm}}/_{\text{min.}}$$

3. INPUT ($^{\text{BTU}}/_{\text{min.}}$)

$$\text{INPUT} = (\dot{m}_f \ ^{\text{lbm}}/_{\text{min.}})(^{\text{BTU}}/_{\text{lbm fuel}})$$

$$= (0.017)(10{,}000) \ ^{\text{BTU}}/_{\text{min.}}$$

$$= 170 \ ^{\text{BTU}}/_{\text{min.}}$$

4. OUTPUT $(\text{BTU}/\text{min.})$

$$\text{OUTPUT} = (\text{HP})(\text{BTU}/\text{HP-min.})$$

$$= (0.262)(42.4)\ \text{BTU}/\text{min.}$$

$$= 11.11\ \text{BTU}/\text{min.}$$

5. SPECIFIC FUEL CONSUMPTION (S.B.F.R.)

$$\text{S.B.F.R.} = \frac{(\text{lbm}/\text{min.})(60\ \text{min}/\text{hr.})}{\text{HP}}$$

$$= \frac{(0.017)(60)}{0.262}\ \text{lbm}/\text{HP-hr.}$$

$$= 3.89\ \text{lbm}/\text{HP-hr.}$$

6. OVERALL THERMAL EFFICIENCY (η)

$$\eta = \frac{\text{OUTPUT}\ \text{BTU}/\text{min.}}{\text{INPUT}\ \text{BTU}/\text{min.}} \times 100\%$$

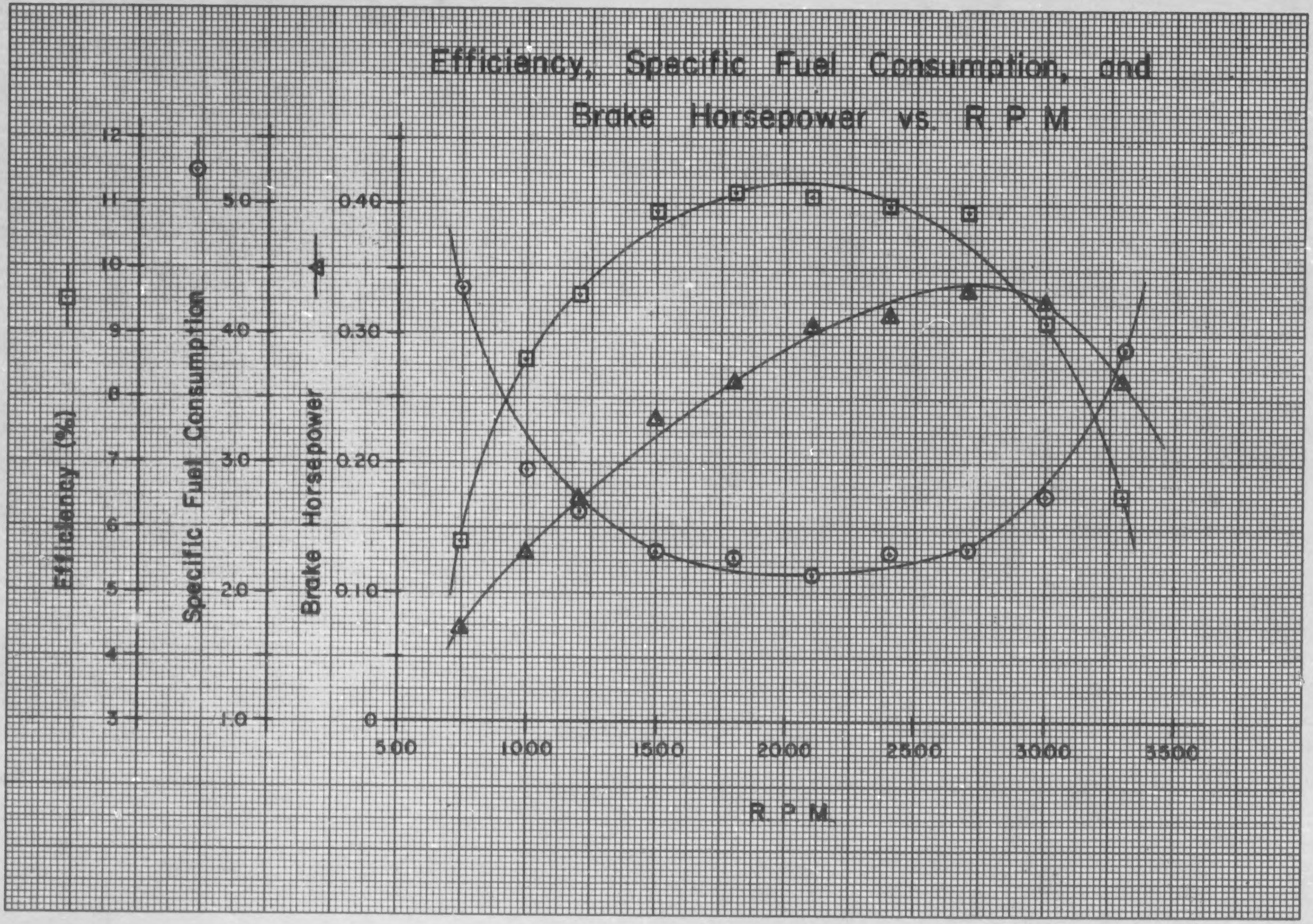
$$= \frac{11.11}{170} \times 100\%$$

$$= 6.5\ \%$$

Results Sheet

RPM	Engine Output		Fuel Flow		Input Btu/min	Specific Fuel Consumption lb/hp-hr	Thermal Efficiency (%)
	Horsepower	Btu/min	grams/min*	lb/min			
3300	0.262	11.11	7.7	0.017	170	3.89	6.5
3000	0.324	13.74	6.7	0.015	150	2.77	9.2
2700	0.334	14.20	5.9	0.013	130	2.34	10.9
2400	0.312	13.20	5.4	0.012	120	2.31	11.0
2100	0.306	12.97	4.9	0.011	110	2.16	11.8
1800	0.263	11.15	4.6	0.010	100	2.28	11.2
1500	0.233	9.87	4.0	0.009	90	2.32	10.9
1200	0.171	7.25	3.4	0.0075	75	2.63	9.6
1000	0.130	5.50	2.9	0.0064	64	2.95	8.6
750	0.073	3.09	2.4	0.0053	53	4.36	5.8

* From Appropriate Curve



Efficiency, Specific Fuel Consumption, and Brake Horsepower vs. R. P. M.

```
      WRITE(3,1000)
 1000 FORMAT(1H1,31X'ENGINE EFFICIENCY'/)
      WRITE(3,1001)
 1001 FORMAT(12X,'RPM',5X,'ENGINE-OUTPUT'3X'FUEL FLOW',5X,'INPUT',
     12X,'SFC (LB/',2X,'THER EFF'/21X,'(HP)',3X,'(B/MIN)',2X,
     2'(LB/MIN)',3X,'(B/MIN)',4X,'HP-HR)',5X,'(PCT)'/)
      DO1009 I=1,10
      READ(2,1002)RPM,TOQ,FUEL
 1002 FORMAT(3F10.0)
C     CALCULATE HORSEPOWER
      HP=TOQ*RPM/63000.
C     CALCULATE FUEL RATE(LB PER MIN)
      FRATE=FUEL/454.
C     CALCULATE ENERGY INPUT(BTU PER MIN)
      FIN=FRATE*10000.
C     CALCULATE OUTPUT(BTU PER MIN)
      OUTP=HP*42.42
C     CALCULATE FUEL CONSUMPTION(LB PER-HP-HR.)
      SBFR=FRATE*60/HP
C     CALCULATE OVERALL THER. EFF.
      ETTA=(OUTP/FIN)*100.
 1009 WRITE(3,1010)RPM,HP,OUTP,FRATE,FIN,SBFR,ETTA
 1010 FORMAT(9X,F6.1,4X,F6.3,4X,F6.2,4X,F6.3,4X,F6.1,4X,F6.2,4X,F6.1)
      CALL EXIT
      END
```

ENGINE EFFICIENCY

RPM	ENGINE-OUTPUT		FUEL FLOW	INPUT	SFC (LB/	THER EFF
	(HP)	(B/MIN)	(LB/MIN)	(B/MIN)	HP-HR)	(PCT)
3300.0	0.261	11.10	0.016	169.6	3.88	6.5
3000.0	0.323	13.73	0.014	147.5	2.73	9.3
2700.0	0.334	14.18	0.012	129.9	2.33	10.9
2400.0	0.312	13.25	0.011	118.9	2.28	11.1
2100.0	0.306	13.00	0.010	107.9	2.11	12.0
1800.0	0.262	11.15	0.010	101.3	2.31	11.0
1500.0	0.233	9.89	0.008	88.1	2.26	11.2
1200.0	0.171	7.27	0.007	74.8	2.62	9.7
1000.0	0.130	5.52	0.006	63.8	2.94	8.6
750.0	0.072	3.08	0.005	52.8	4.36	5.8

Data Sheet

Ignition Setting	RPM	Torque (in-lb)	Manifold Pressure (psig)	Cylinder Pressure (psig)
20° Advanced	3000	5.8	5.5	45
	2600	8.5	5.0	40
	2200	10.8	4.1	59
	1800	11.9	3.9	62
	1400	12.6	3.6	62
	1000	8.7	3.0	58
10° Advanced	3000	5.0	5.0	42
	2600	8.0	4.8	46
	2200	9.9	4.0	63
	1800	11.0	3.75	66
	1400	12.1	2.7	58
	1000	10.4	2.4	82
0°	3000	3.75	3.0	40
	2600	7.0	2.7	39
	2200	7.8	2.5	52
	1800	9.0	2.3	44
	1400	12.0	2.0	48
	1000	11.0	1.26	50

Data Sheet

Ignition Setting	RPM	Torque (in - lb)	Manifold Pressure (psig)	Cylinder Pressure (psig)
10° Retard	2860	3.0	2.8	33
	2600	4.8	2.3	38
	2200	7.2	1.6	42
	1800	9.0	1.5	47
	1400	10.9	1.4	46
	1000	9.7	0	49
20° Retard	2500	3.5	5.0	35
	2200	5.0	3.9	42
	1900	6.2	2.9	40
	1600	8.2	2.6	42
	1300	8.7	2.4	44
	1000	8.3	2.2	45

SAMPLE CALCULATIONS

1. HORSEPOWER (HP)

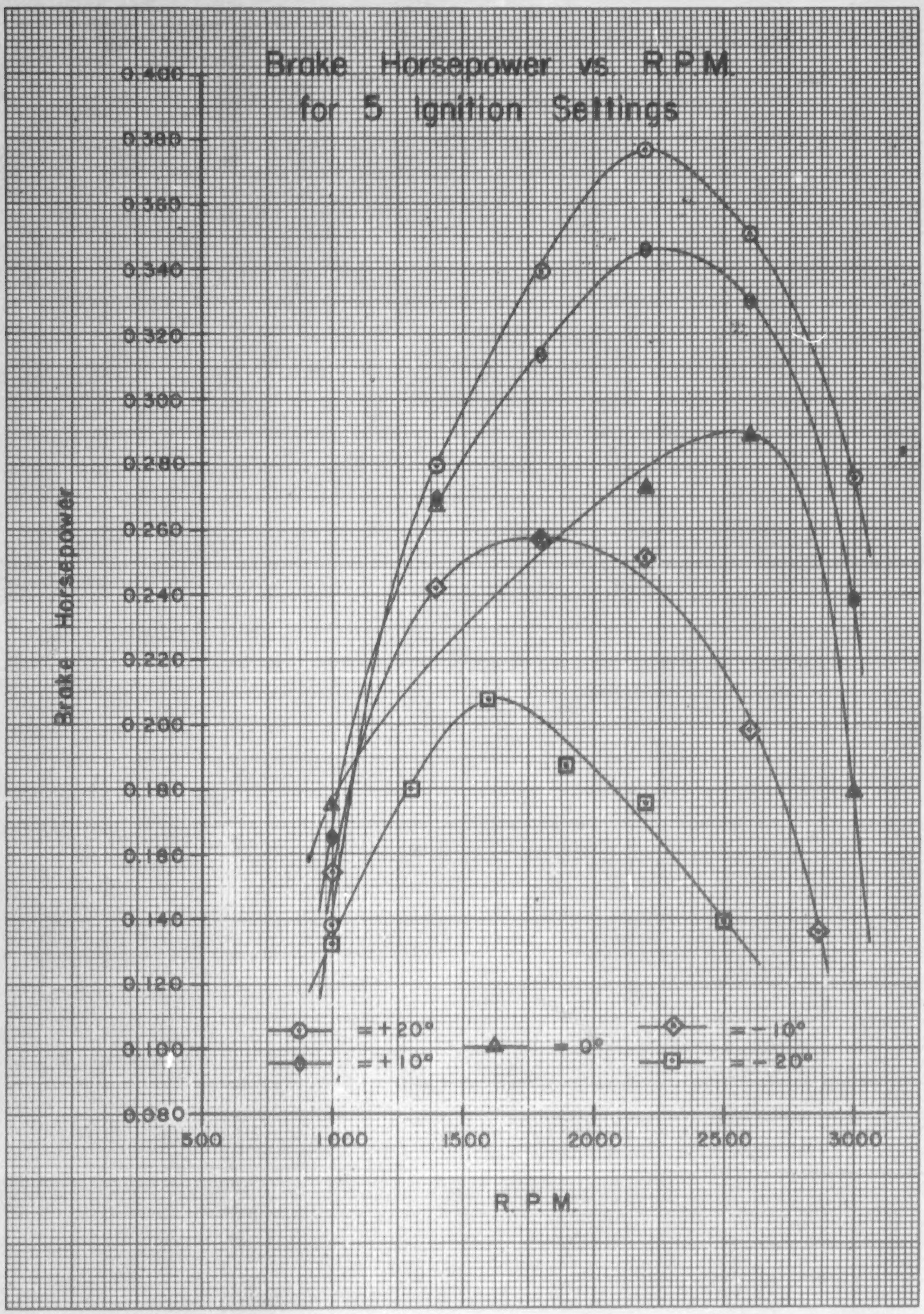
$$HP = \frac{T\ N}{63{,}000}$$

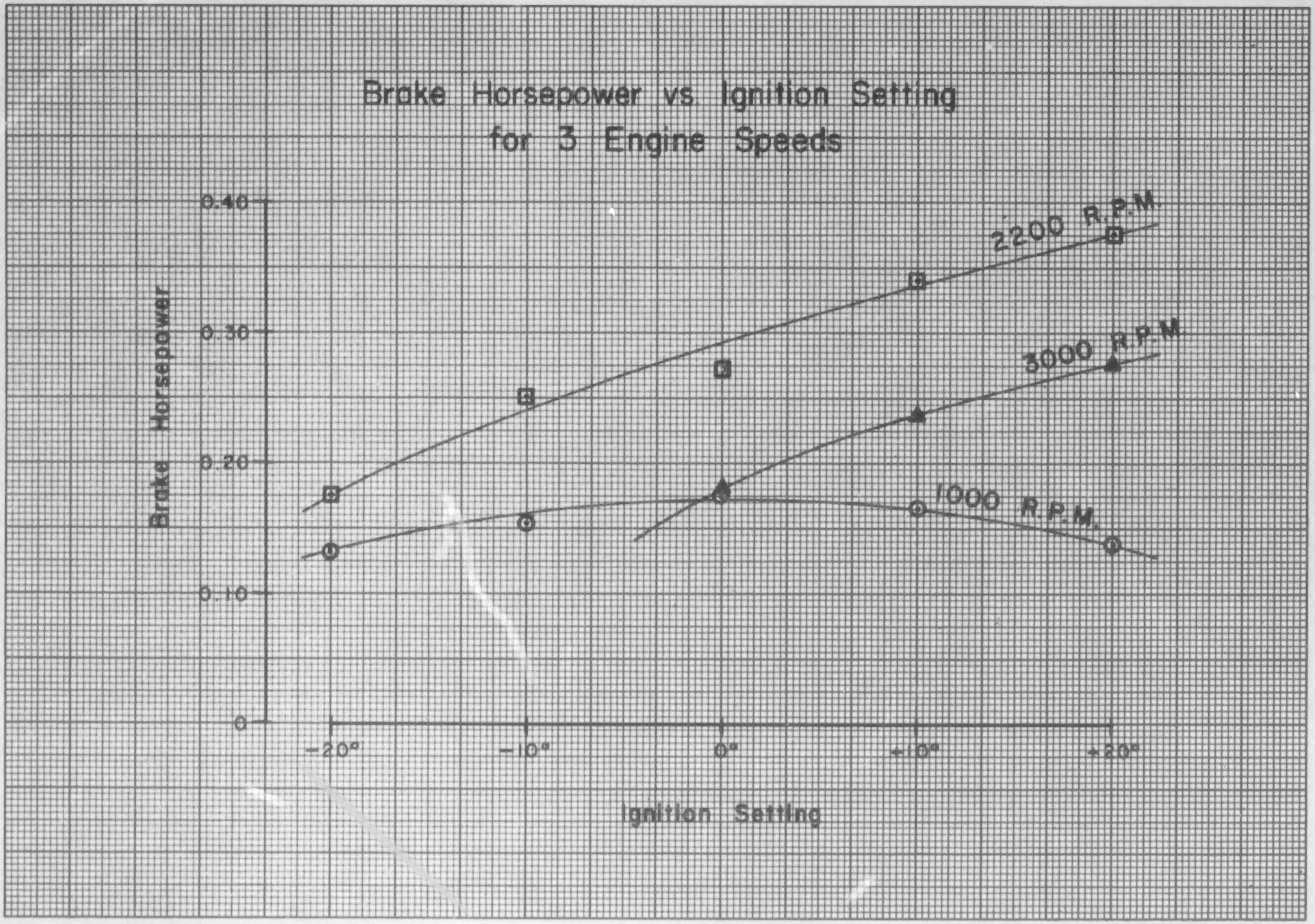
$$= \frac{(5.8 \text{ in.-lb.})(3000 \text{ RPM})}{63000\ \frac{\text{in.-lb.}}{\text{min.}}}$$

$$= 0.276$$

Results Sheet

RPM	Horsepower				
	+20°	+10°	0°	-10°	-20°
3000	0.276	0.238	0.179		
2600	0.351	0.330	0.289	0.198	
2200	0.377	0.346	0.272	0.251	0.175
1800	0.340	0.314	0.257	0.257	
1400	0.280	0.269	0.267	0.242	
1000	0.138	0.165	0.175	0.154	0.132


Brake Horsepower vs. R.P.M.
for 5 Ignition Settings
Brake Horsepower
0.400
0.380
0.360
0.340
0.320
0.300
0.280
0.260
0.240
0.220
0.200
0.180
0.160
0.140
0.120
0.100
0.080
500
1000
1500
2000
2500
3000
R. P. M.
⊙ = +20°
◆ = +10°
▲ = 0°
◇ = − 10°
⊡ = − 20°



Brake Horsepower vs. Ignition Setting for 3 Engine Speeds

SAMPLE CALCULATIONS

I. HORSEPOWER (HP)

$$HP = \frac{T\ N}{63{,}000}$$

$$= \frac{\left(5.1\ \frac{\text{in.-lb}}{\text{Rev.}}\right)\left(3000\ \text{Rev./min.}\right)}{63{,}000\ \frac{\text{in.-lb}}{\text{HP-min.}}}$$

$$= 0.243\ \text{HP}$$

II. FUEL RATE (lbm/min.)

a) ALCOHOL & GASOLINE

$$\frac{7.1\ \text{gm/min.}}{454\ \text{gm/lbm}} = 0.0156\ \text{lbm/min.}$$

NOTE: gm/min. determined from appropriate curve

b) PROPANE

$$\frac{\left(2\ \text{gm}/29\ \text{sec}\right)\left(60\ \frac{\text{sec}}{\text{min.}}\right)}{454\ \text{gm/lbm}} = 0.0091\ \text{lbm/min.}$$

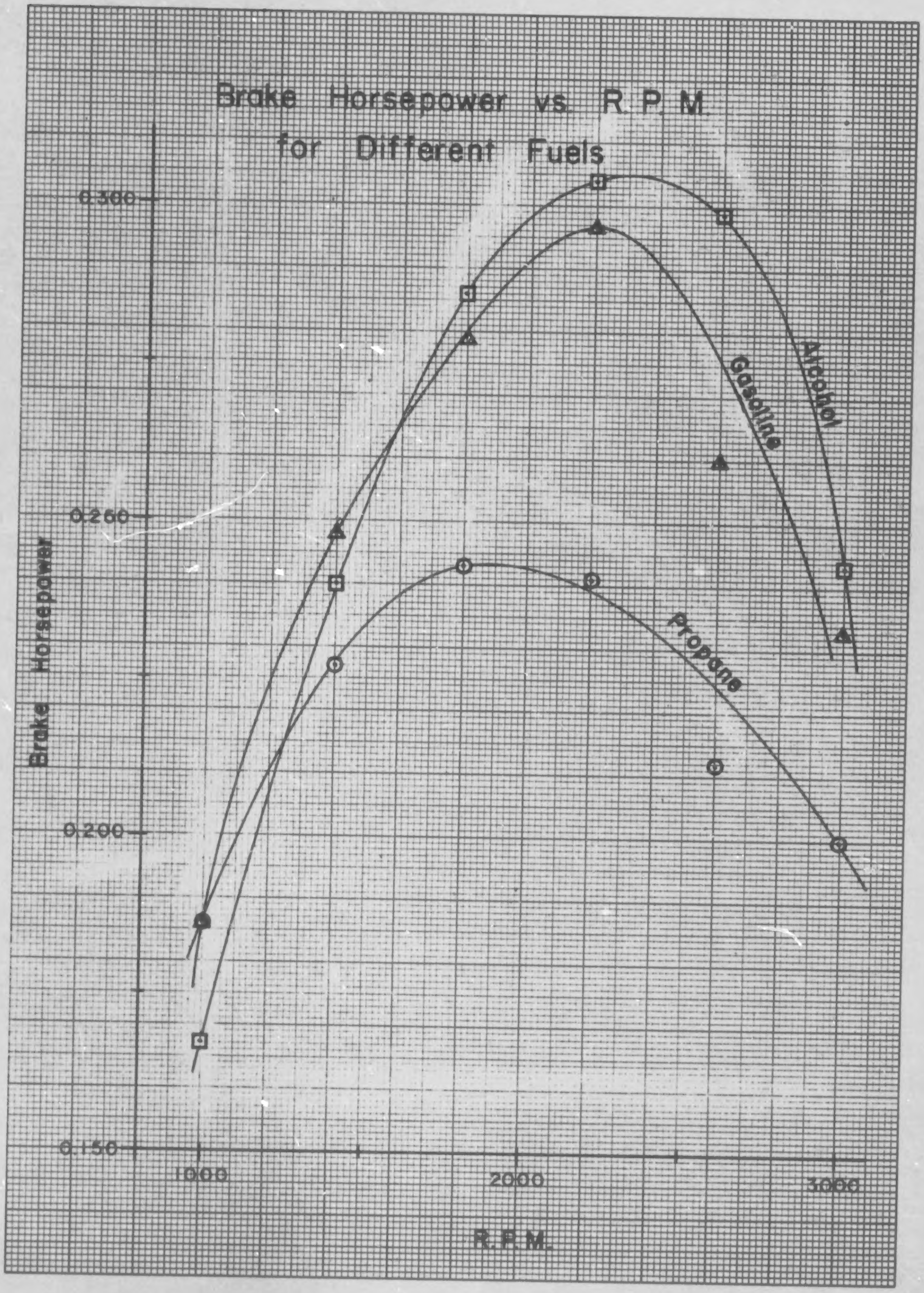
Data Sheet

Fuel	RPM	Torque (in-lb)	Manifold Pressure psig	Cylinder Pressure psig	Fuel Rate mm/min
Alcohol	3000	5.10	7.0	47	9.95
	2600	7.25	5.0	56	9.60
	2200	8.70	3.6	63	8.50
	1800	10.0	3.5	72	8.20
	1400	10.8	2.5	85	7.20
	1000	10.5	5.0	97	6.50
Gasoline	3000	4.90	4.2	47	4.30
	2600	6.30	3.0	57	4.00
	2200	8.50	3.9	70	4.00
	1800	9.75	3.0	84	3.70
	1400	11.2	1.8	94	3.00
	1000	11.7	0	100	2.30

Fuel	RPM	Torque (in-lb)	Manifold Pressure psig	Cylinder Pressure psig	Fuel Weight lbs	Time sec.
Propane	3000	4.20	4.0	42	4.4×10^{-3}	29
	2600	5.15	2.9	52	"	32
	2200	6.90	2.6	63	"	39
	1800	8.50	4.4	73	"	46
	1400	10.2	3.0	82	"	50
	1000	11.7	0.5	96	"	50

Results Sheet

RPM	Alcohol		Gasoline		Propane	
	Horsepower	Fuel Rate lbs/min	Horsepower	Fuel Rate lbs/min	Horsepower	Fuel Rate lbs/min
3000	0.243	0.0156	0.233	0.0055	0.200	0.0091
2600	0.299	0.0148	0.260	0.0050	0.212	0.0082
2200	0.304	0.0123	0.297	0.0050	0.241	0.0068
1800	0.286	0.0116	0.279	0.0046	0.243	0.0058
1400	0.240	0.0094	0.248	0.0040	0.227	0.0053
1000	0.167	0.0081	0.186	0.0022	0.186	0.0053


Brake Horsepower vs. R. P. M.
for Different Fuels
0.300
0.260
0.200
0.150
1000
2000
3000
R. P. M.
Brake Horsepower
Alcohol
Gasoline
Propane

Data Sheet

Throttle Setting	RPM	Torque in-lb	Manifold Pressure psig	Cylinder Pressure psig	Fuel Rate gm/min	Air Rate cu. ft./hr.
Fully Open	3000	2.50	2.0	47	1.70	89
	2600	7.00	2.0	58	1.45	87
	2200	8.10	2.5	60	1.10	82
	1720	9.00	4.0	97	1.20	76
3/4 Open	2600	4.00	7.4	47	1.50	82
	2280	6.00	6.8	60	1.50	79
	2000	7.00	6.5	74	1.30	76
	1540	9.10	5.0	100	1.05	70
1/2 Open	2280	3.75	10.0	36	1.10	60
	1980	5.50	9.0	51	0.90	56
	1720	6.20	8.0	66	1.00	53
	1380	8.00	6.6	82	0.70	50
1/4 Open	1470	2.00	11.8	37	0.35	23
	1280	4.25	10.4	45	0.25	22
	1000	6.40	9.0	72	0.20	21
	800	6.80	7.5	92	0.15	20

Barometer Pressure 29.84 in. Hg Room Temperature 70°F

SAMPLE CALCULATIONS

1. HORSEPOWER (HP)

$$HP = \frac{T\,N}{63{,}000}$$

$$= \frac{(2.5\ \text{in-lb/rev.})(3000\ \text{rev/min.})}{63{,}000\ \frac{\text{in-lb}}{\text{HP-min.}}}$$

$$= 0.119\ \text{HP}$$

2. FUEL RATE (lbm/hr.)

$$\text{FUEL RATE} = \frac{(1.7\ \text{gm/min.})(60\ \text{min./hr.})}{454\ \text{gm/lbm}}$$

$$= 0.224\ \text{lbm/hr.}$$

3. SPECIFIC FUEL CONSUMPTION (lbm/HP-hr.)

$$SFC = \frac{\text{FUEL RATE}}{\text{HP}}$$

$$= \frac{0.224\ \text{lbm/hr.}}{0.119\ \text{HP}}$$

$$= 1.886\ \text{lbm/HP-hr.}$$

4. VOLUMETRIC EFFICIENCY (η_v)

$$\eta_v = \frac{V_{ACT} \ (\text{ft}^3/\text{hr.})}{V_D \ (\text{ft}^3/\text{hr.})}$$

$$V_D = \frac{ALN}{1728} C$$

where: V_D = VOLUMETRIC DISPLACEMENT ($\text{ft}^3/\text{hr.}$)
A = CYLINDER AREA (in.^2)
L = PISTON STROKE (in.)
N = AIR INTAKE RATE (strokes/min.)
C = NUMBER OF CYLINDERS

$$V_D = \frac{\left(\frac{\pi}{4}[1.625]^2 \text{in.}^2\right)(2 \text{ in.})\left(\frac{1500 \text{ rev./min.}}{2}\right)}{1728 \ \text{in}^3/\text{ft.}^3}(1)(60 \ \text{min}/\text{hr.})$$

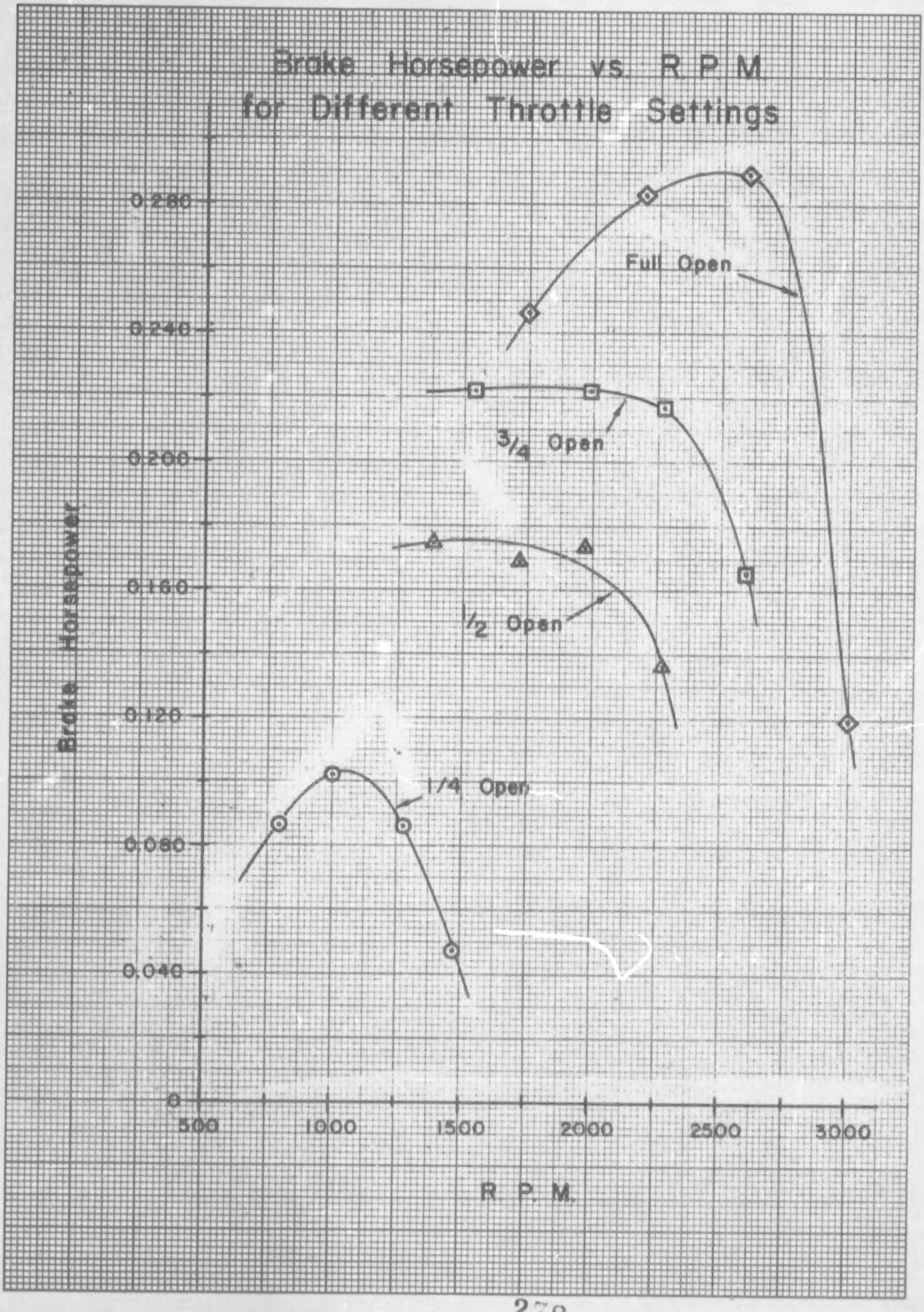
$$= 215.9 \ \text{ft}^3/\text{hr.}$$

$$\eta_v = \frac{89 \ \text{ft}^3/\text{hr.}}{215.9 \ \text{ft}^3/\text{hr.}}$$

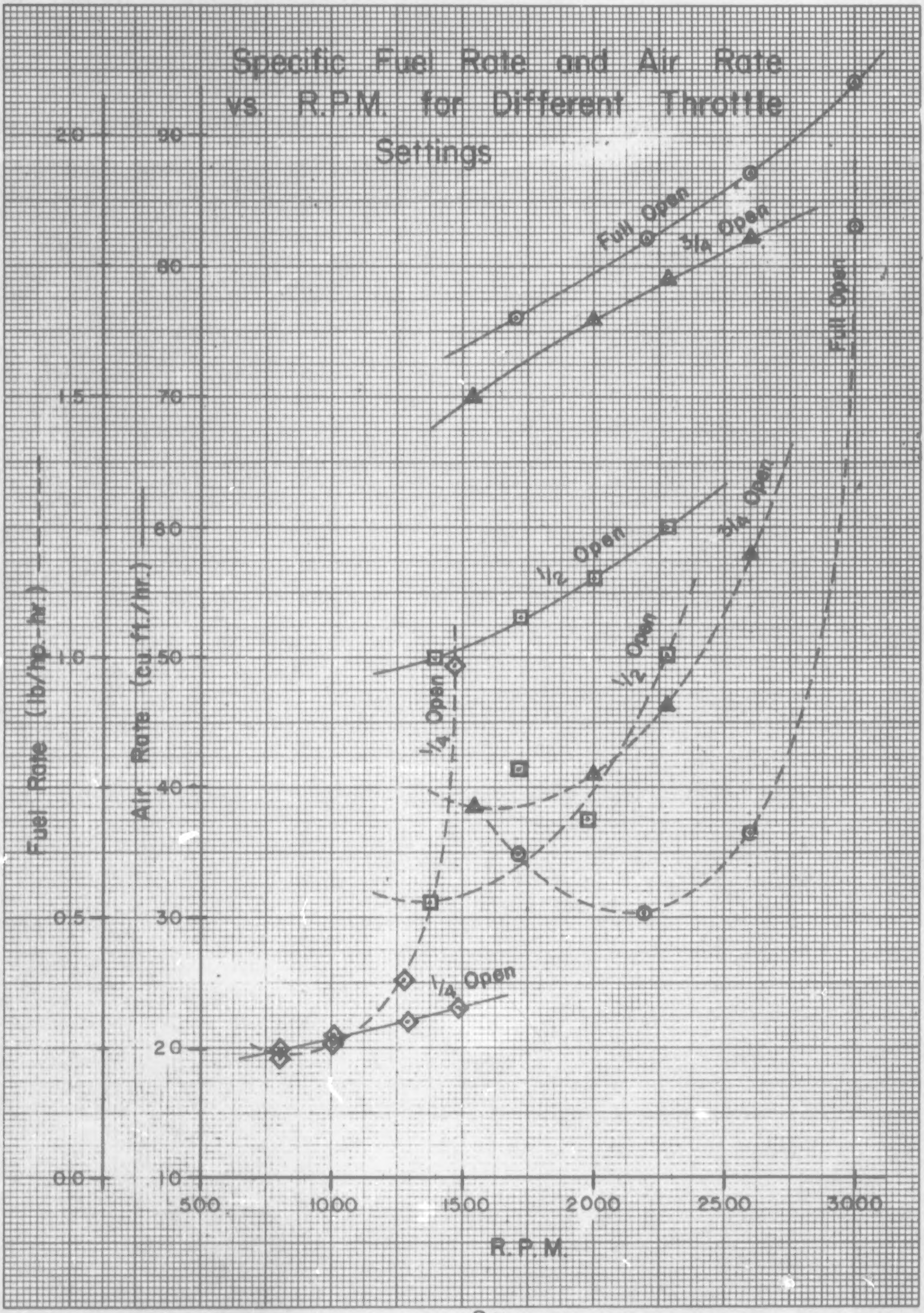
$$= 0.412 \qquad [\times 100\% = 41.2\%]$$

Results Sheet

Throttle Settings	RPM	Horsepower	Specific Fuel Rate lbm/hp-hr.	Air Rate cu.ft./hr	Volumetric Efficiency
Fully Open	3000	0.119	1.886	89	0.412
	2600	0.289	0.662	87	0.465
	2200	0.283	0.513	82	0.518
	1720	0.246	0.644	76	0.614
3/4 Open	2600	0.165	1.200	82	0.439
	2280	0.217	0.912	79	0.482
	2000	0.222	0.773	76	0.528
	1540	0.222	0.624	70	0.632
1/2 Open	2280	0.136	1.068	60	0.366
	1980	0.173	0.687	56	0.393
	1720	0.169	0.781	53	0.428
	1380	0.175	0.528	50	0.504
1/4 Open	1470	0.047	0.983	23	0.217
	1280	0.086	0.384	22	0.239
	1000	0.102	0.259	21	0.292
	800	0.086	0.230	20	0.347



Brake Horsepower vs. R.P.M. for Different Throttle Settings



Specific Fuel Rate and Air Rate vs. R.P.M. for Different Throttle Settings

```
C     TOQ TORQUE IN-LBS
C     FRATE FUEL RATE MM/MIN
C     ARATE AIR RATE CUBIC FT/HR
C     S.F.C. SPECIFIC FUEL RATE LB/HP-HR
      WRITE(3,6000)
 6000 FORMAT(1H1,27X,'AIR FUEL RATIO'/)
      WRITE(3,6001)
 6001 FORMAT(12X,'RPM',5X,'HORSE',3X,'SFC (LB',2X,'AIR RATE',3X,
     1'VOL EFF'/20X,'POWER',3X,'/HP-HR)',2X,'(FT3/HR)'5X,'(PCT)' )
      BORE=1.625
      STROK=2.0
      C=1.0
      DO 7 I 1,16
      READ(2,6003)RPM,TOQ,FRATE,ARATE
 6003 FORMAT(4F10.0)
C     CALCULATE HORSEPOWER
      HP=TOQ*RPM/63000.
C     CALCULATE FUEL RATE LB/HR
      FR=FRATE*60./454.
C     CALCULATE SPECIFIC FUEL CONSUMPTION LB/HP-HR
      SFC=FR/HP
C     CALCULATE VOLUMETRIC DISPLACEMENT CU FT/HR
      VD=(.7854)*1.625**2.*2.0*RPM /(1728.*2.)*60.
C     CALCULATE VOLUMETRIC EFFICIENCY
      ETAV=ARATE/VD*100.
      IF(I-1)1,2,1
 2    WRITE(3,11)
 11   FORMAT(/28X,'FULL OPEN THROTTLE'/)
      GO TO 20
 1    IF(I-5)3,4,3
 4    WRITE(3,12)
 12   FORMAT(/28X,'3/4 OPEN THROTTLE'/)
      GO TO 20
 3    IF(I-9)5,6,5
 6    WRITE(3,13)
 13   FORMAT(/28X,'1/2 OPEN THROTTLE'/)
      GO TO 20
 5    IF(I-13)20,8,20
 8    WRITE(3,14)
 14   FORMAT(/28X,'1/4 OPEN THROTTLE')
      GO TO 20
 20   WRITE(3,15)RPM,HP,SFC,ARATE,ETAV
  15  FORMAT(9X,F6.1,2(4X,F6.3),4X,F6.1,4X,F6.3)
    7 CONTINUE
      CALL EXIT
      END
```

AIR FUEL RATIO

RPM	HORSE POWER	SFC (LB /HP-HR)	AIR RATE (FT3/HR)	VOL EFF (PCT)
		FULL OPEN THROTTLE		
3000.0	0.119	1.887	89.0	41.196
2600.0	0.288	0.663	87.0	46.466
2200.0	0.282	0.513	82.0	51.759
1720.0	0.245	0.645	76.0	61.359
		3/4 OPEN THROTTLE		
2600.0	0.165	1.200	82.0	43.796
2280.0	0.217	0.912	79.0	48.115
2000.0	0.222	0.773	76.0	52.768
1540.0	0.222	0.623	70.0	63.120
		1/2 OPEN THROTTLE		
2280.0	0.135	1.071	60.0	36.543
1980.0	0.172	0.688	56.0	39.275
1720.0	0.169	0.780	53.0	42.790
1380.0	0.175	0.527	50.0	50.313
		1/4 OPEN THROTTLE		
1470.0	0.046	0.991	23.0	21.727
1280.0	0.086	0.382	22.0	23.867
1000.0	0.101	0.260	21.0	29.161
800.0	0.086	0.229	20.0	34.716

Data Sheet

Comp. Ratio	RPM	Torque in-lb	Manifold Pressure psig	Cylinder Pressure psig	Fuel Rate mm/min
3 to 1	3070	5.8	4.0	59	9.9
	2650	7.2	3.0	87	9.8
	2320	8.8	2.5	102	9.7
	2040	10.1	2.0	80	8.5
	1675	9.2	2.0	100	8.5
4 to 1	3040	7.0	4.0	63	11.5
	2600	8.3	2.5	78	10.5
	2280	9.9	2.0	105	9.1
	2040	10.9	2.0	83	8.6
	1660	12.0	2.0	105	8.0

Fuel Used ALCOHOL Heating Value 12,300 BTU/lbm

SAMPLE CALCULATIONS

1. HORSEPOWER

$$HP = \frac{T\ N}{63{,}000}$$

$$= \frac{(5.8 \text{ in.-lb.})(3070 \ ^{\text{rev.}}/_{\text{min.}})}{63{,}000 \ \frac{\text{in.-lb.}}{\text{HP-min.}}}$$

$$= 0.283 \text{ HP}$$

2. FUEL RATE ($^{\text{lbm}}/_{\text{hr.}}$)

$9.9 \ ^{\text{mm}}/_{\text{min.}} = 7.1 \ ^{\text{gm}}/_{\text{min.}}$ (FROM APPROPRIATE CURVE)

$$\text{FUEL RATE} = \frac{(7.1 \ ^{\text{gm}}/_{\text{min.}})(60 \ ^{\text{min.}}/_{\text{hr.}})}{454 \ ^{\text{gm}}/_{\text{lbm}}}$$

$$= 0.938 \ ^{\text{lbm}}/_{\text{hr.}}$$

3. THERMAL EFFICIENCY (η_T)

$$\eta_T = \frac{(\text{HP})(2545 \ ^{\text{BTU}}/_{\text{HP-hr.}})}{(^{\text{lbm}}/_{\text{hr.}})(\text{HHV})} \times 100\%$$

$$= \frac{(0.283 \text{ HP})(2545 \ ^{\text{BTU}}/_{\text{HP-hr.}})}{(0.938 \ ^{\text{lbm}}/_{\text{hr.}})(12{,}300 \ ^{\text{BTU}}/_{\text{lbm}})} \times 100\%$$

$$= 6.24\%$$

4. SPECIFIC FUEL CONSUMPTION ($^{\text{lbm}}/_{\text{HP-hr.}}$)

$$\text{SFC} = \frac{0.938 \ ^{\text{lbm}}/_{\text{hr.}}}{0.283 \text{ HP}}$$

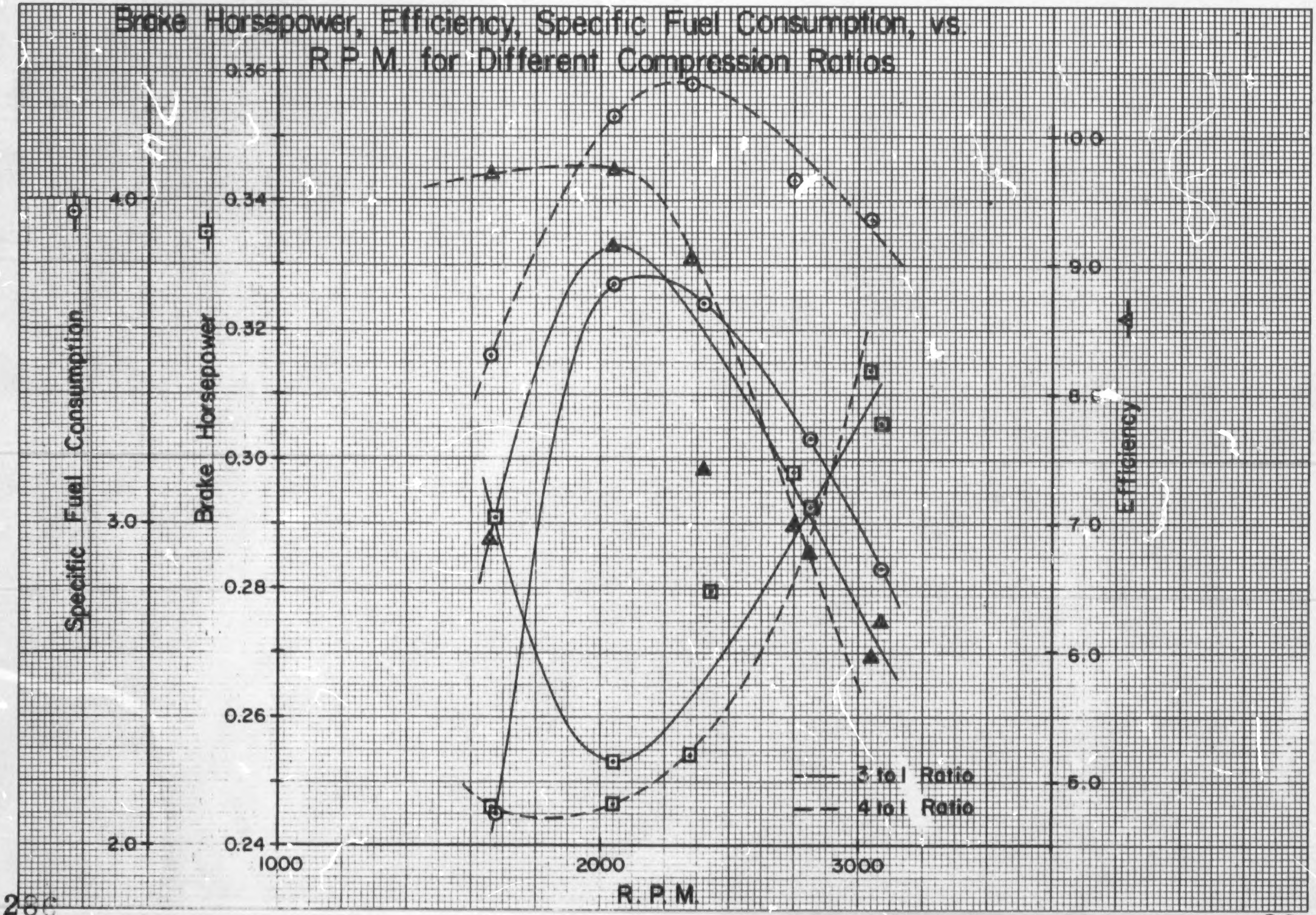
$$= 3.31 \ ^{\text{lbm}}/_{\text{HP-hr.}}$$

Results Sheet

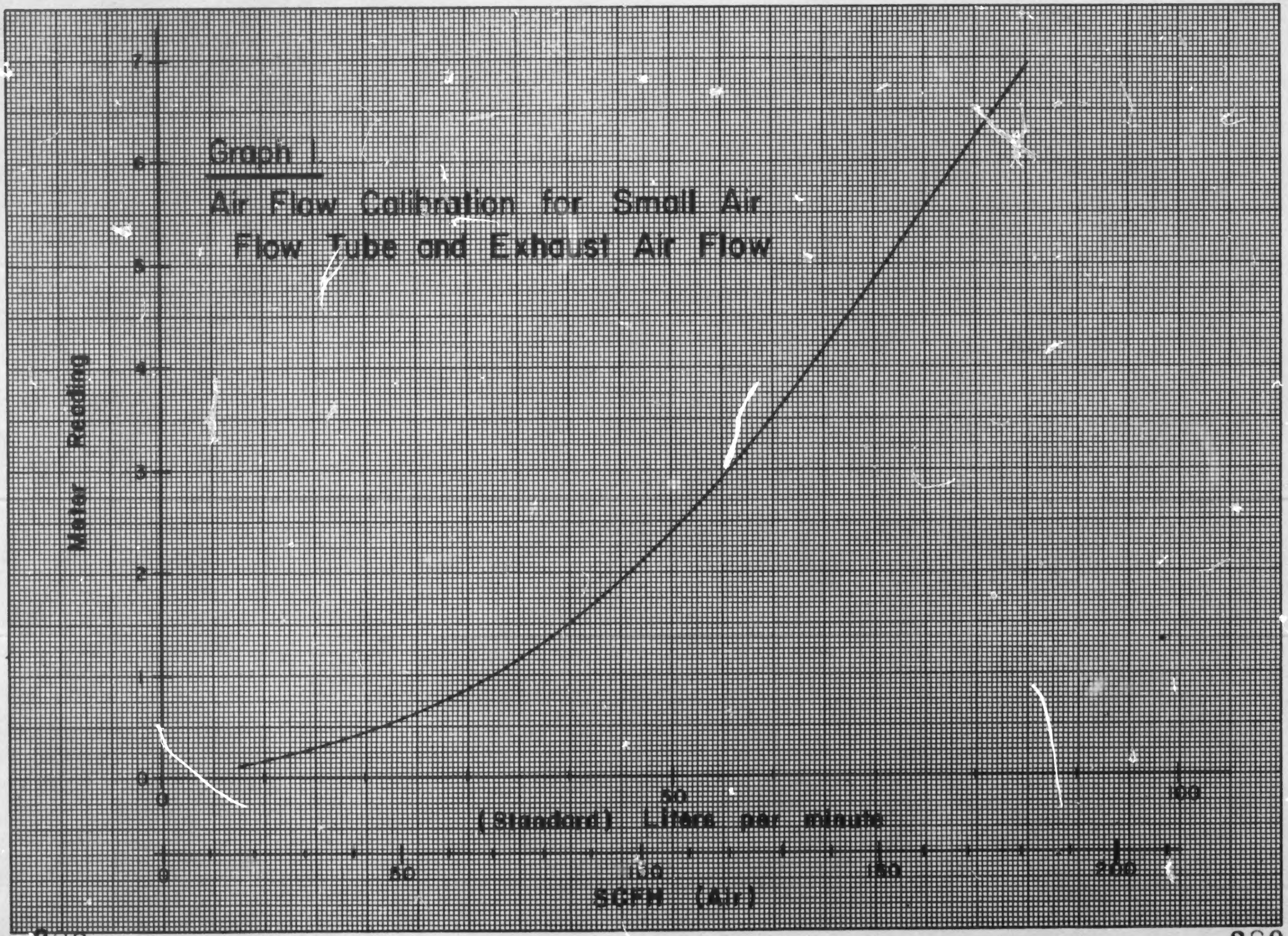
RPM	3 to 1 Compression Ratio			4 to 1 Compression Ratio		
	Horsepower	Thermal Efficiency	sfc lbs/hp-hr	Horsepower	Thermal Efficiency	sfc lbs/hp-hr
3070	0.283	6.24 %	3.31			
2650	0.303	6.78	3.05			
2320	0.324	7.41	2.79			
2040	0.327	9.15	2.26			
1675	0.245	6.86	3.02			

Results Sheet

RPM	3 to 1 Compression Ratio			4 to 1 Compression Ratio		
	Horsepower	Thermal Efficiency	sfc lbs/hp-hr	Horsepower	Thermal Efficiency	sfc lbs/hp-hr
3040				0337	5.96 %	3.47
2600				0.343	6.99	2.96
2280				0.358	9.05	2.28
2040				0.353	9.72	2.13
1660				0.316	9.71	2.12

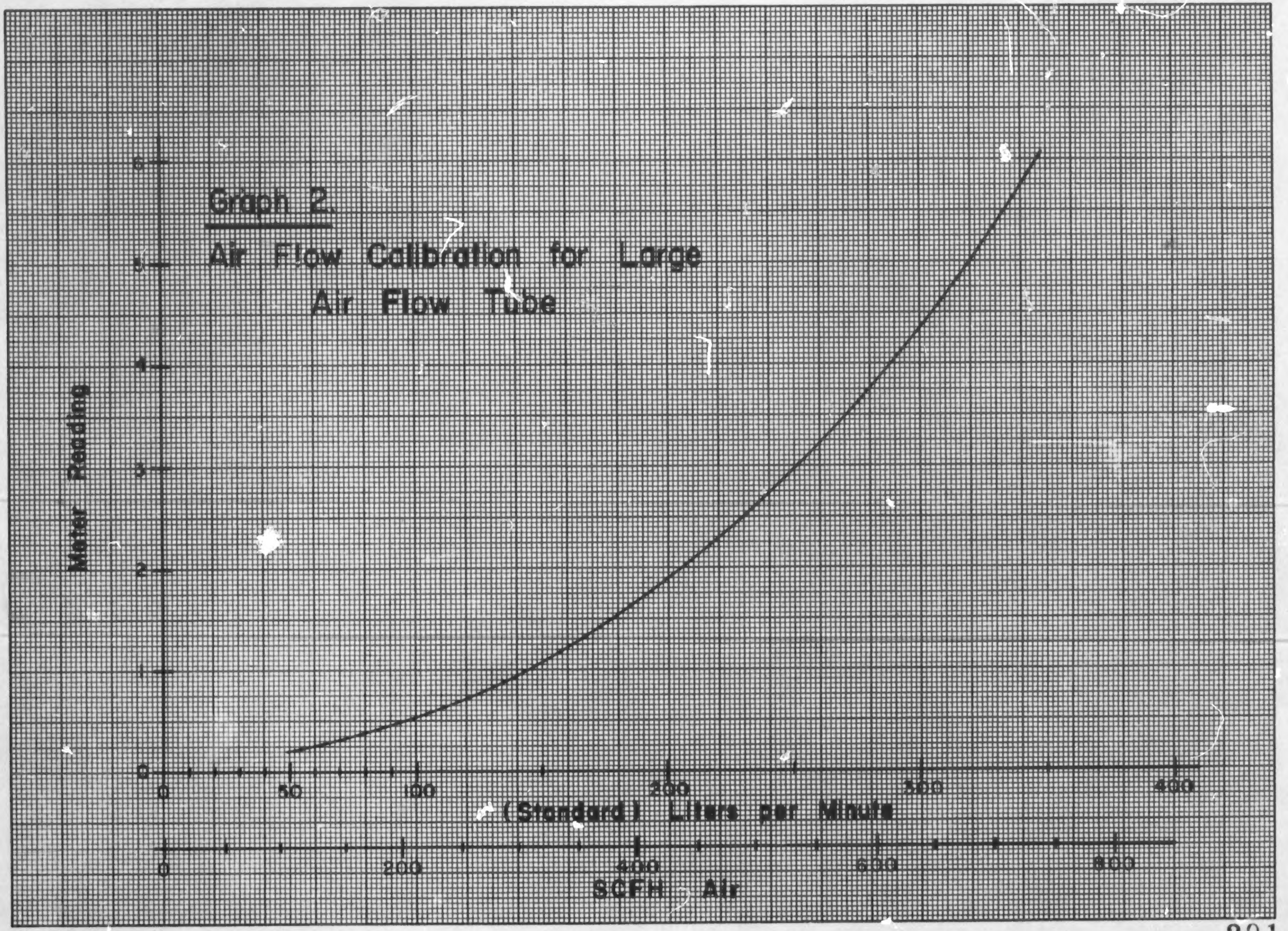


Brake Horsepower, Efficiency, Specific Fuel Consumption, vs. R.P.M. for Different Compression Ratios



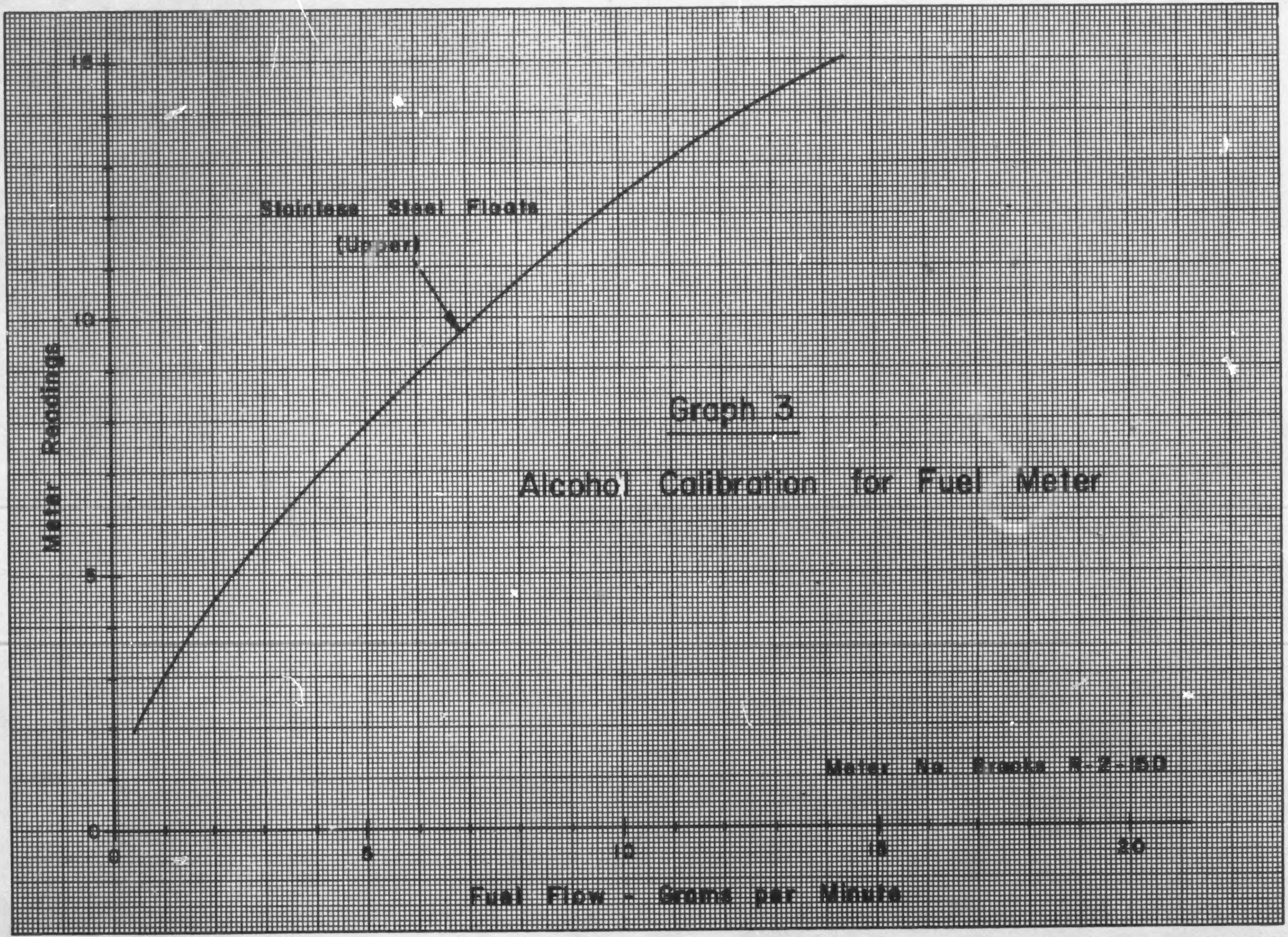
Graph I.

Air Flow Calibration for Small Air Flow Tube and Exhaust Air Flow



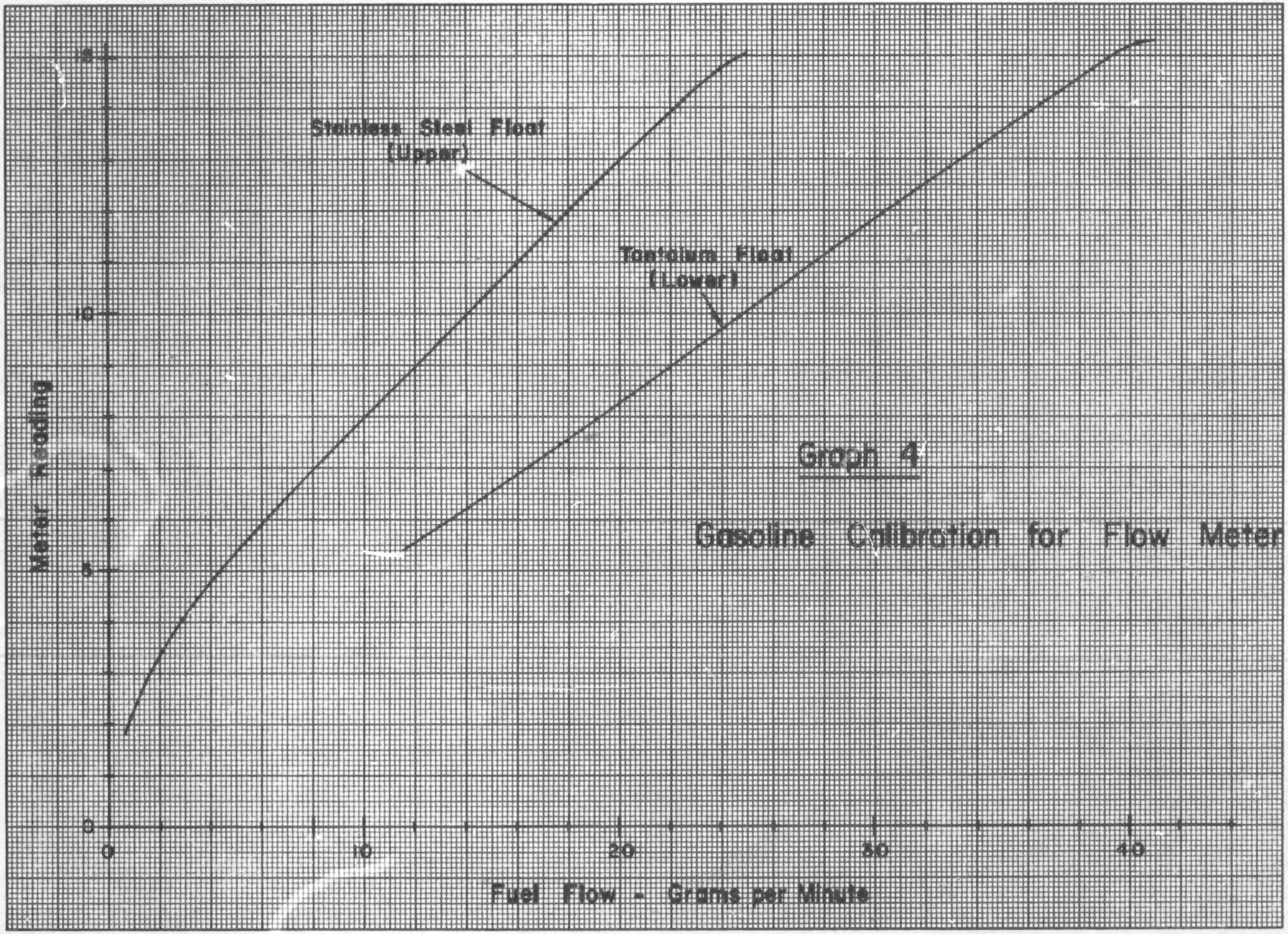
Graph 2.

Air Flow Calibration for Large Air Flow Tube



Graph 3

Alcohol Calibration for Fuel Meter



Graph 4

Gasoline Calibration for Flow Meter

EXPERIMENT NO. 18

VAPOR COMPRESSION SYSTEMS

A - SYSTEM ANALYSIS
B - MECHANICAL SERVICING
C - SYSTEM TONNAGE

Data and Results Sheet

Location	Name of Component
A	COMPRESSOR
B	RECEIVER
C	EXPANSION VALVE
D	FEELER BULB
E	EVAPORATOR
F	CONDENSER
G	LOW SIDE SERVICE VALVE
H	HIGH SIDE SERVICE VALVE
I	SIGHT GLASS
J	DRIER
K	KING VALVE

Location	Pressure PSIG	Temperature °F	Enthalpy
Compressor Suction	35	46	82.53
Compressor Discharge	125	128	91.75
Expansion Valve Inlet	125	90	28.71
Evaporator Exit	38	49	83.00

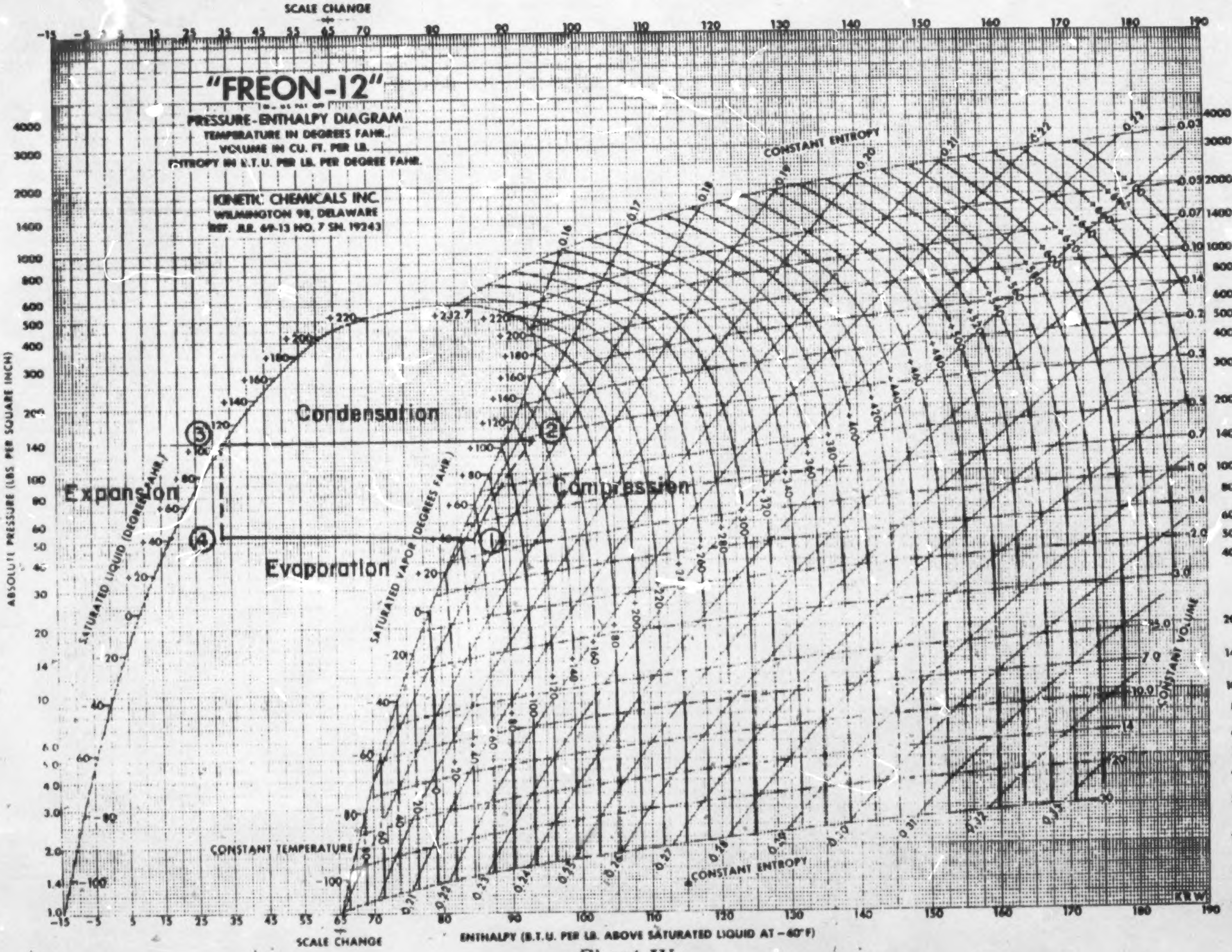

SCALE CHANGE
"FREON-12"
PRESSURE-ENTHALPY DIAGRAM
TEMPERATURE IN DEGREES FAHR.
VOLUME IN CU. FT. PER LB.
ENTROPY IN B.T.U. PER LB. PER DEGREE FAHR.
KINETIC CHEMICALS INC.
WILMINGTON 98, DELAWARE
REF. J.R. 69-13 NO. 7 SH. 19243
CONSTANT ENTROPY
Condensation
Expansion
Compression
Evaporation
③
②
④
①
SATURATED LIQUID (DEGREES FAHR.)
SATURATED VAPOR (DEGREES FAHR.)
CONSTANT TEMPERATURE
CONSTANT VOLUME
CONSTANT ENTROPY
ABSOLUTE PRESSURE (LBS PER SQUARE INCH)
ENTHALPY (B.T.U. PER LB. ABOVE SATURATED LIQUID AT -40°F)
SCALE CHANGE
-15
-5
5
15
25
35
45
55
65
70
80
90
100
110
120
130
140
150
160
170
180
190
4000
3000
2000
1400
1000
800
600
500
400
300
200
140
100
80
60
50
40
30
20
14
10
8.0
6.0
5.0
4.0
3.0
2.0
1.4
1.0
+232.7
K.R.W.

Chart IV

Data Sheet

Air Side **Water Side**

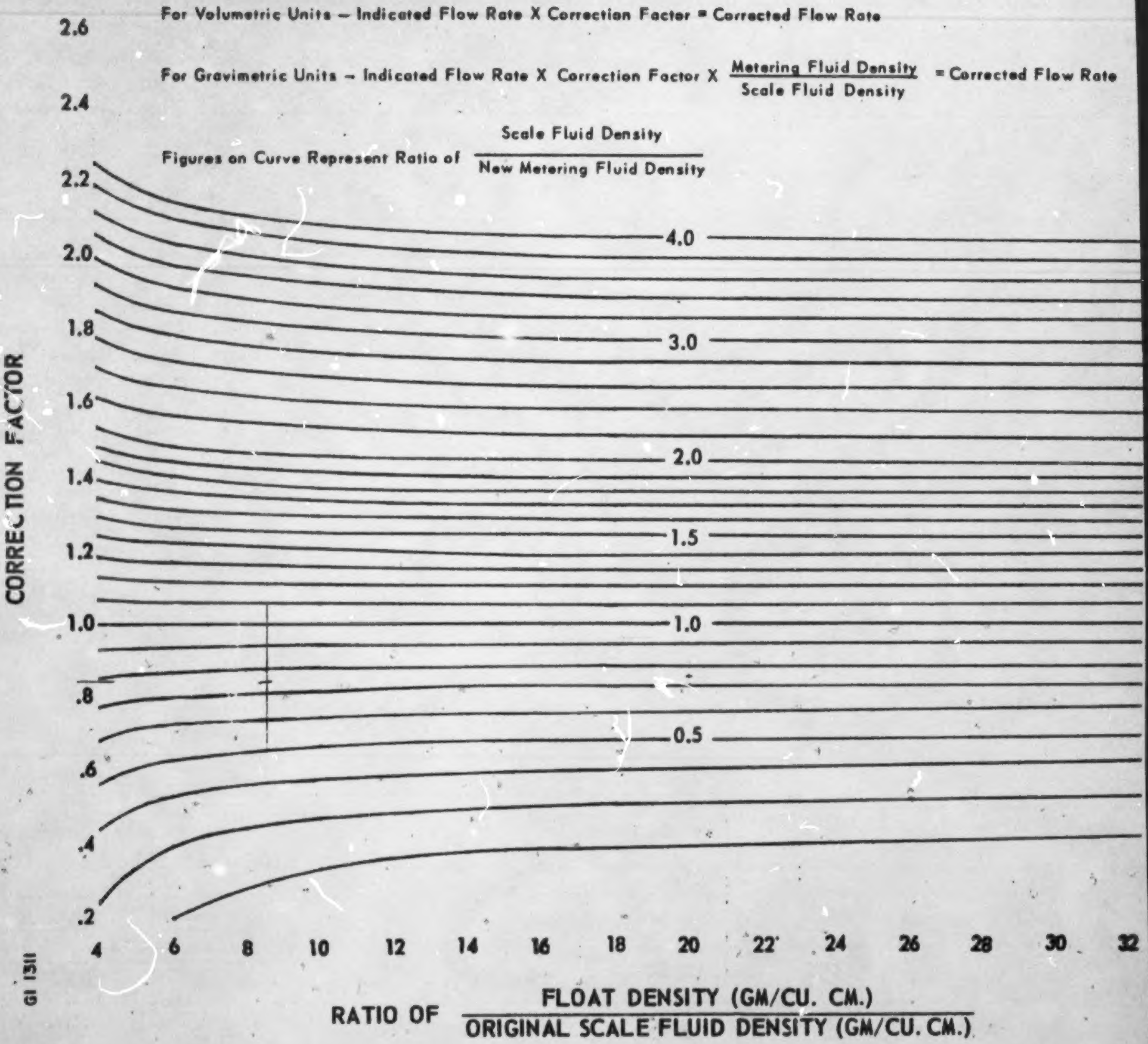
Time	Temperature (°F)				Duct Velocity fpm	Condenser Water Temp. (°F)	
	Dry Bulb (In)	Wet Bulb (In)	Dry Bulb (Out)	Wet Bulb (Out)		In	Out
0	76.0	66.0	69.5	61.5	512	70	84
mid.	79.0	67.0	68.5	61.5	534	70	84
end	78.0	67.0	66.0	61.5	554	70	84
average	77.6	66.6	68.0	61.5	532	70	84

Anemometer Correction 0.995 Duct Area 4.25 sq. ft. Meter Reading Intial 49352.0

Rotameter Correction 0.84 Final 49377.2

Refrigeration Side

Time	Pressure (psig)			Temperature (°F)		Rotameter Reading gpm
	Comp Suct	Comp Disch	Evaporator	Exp. Valve (In)	Evaporator (Out)	
0	38	125	42	81.0	52.0	1.60
mid	38	125	43	82.0	52.0	1.40
end	38	125	41	82.0	50.0	1.50
average	38	125	42	81.6	51.3	1.50



For Volumetric Units – Indicated Flow Rate X Correction Factor = Corrected Flow Rate

For Gravimetric Units – Indicated Flow Rate X Correction Factor X $\frac{\text{Metering Fluid Density}}{\text{Scale Fluid Density}}$ = Corrected Flow Rate

Figures on Curve Represent Ratio of $\frac{\text{Scale Fluid Density}}{\text{New Metering Fluid Density}}$

SAMPLE CALCULATIONS

I. AIR SIDE

1. ENTHALPY (FROM PSYCHROMETRIC CHART)

a) $h_{in.}$ @ 77.6 °F D.B. & 66.6 °F W.B.

$= 31.5 \ ^{BTU}/_{lbm}$

b) $h_{out.}$ @ 68.0 °F D.B. & 61.5 °F W.B.

$= 27.6 \ ^{BTU}/_{lbm}$

2. DENSITY AT EXIT

$144 P v = RT \qquad \rho = \frac{1}{v}$

$\therefore \ \rho = \frac{144 P}{RT}$

$$= \frac{(144 \ ^{in^2}/_{ft^2})(14.69 \ ^{lbf}/_{in.^2})}{(53.3 \ \frac{ft\text{-}lbf}{lbm\text{-}°R})(68.0 + 460 \ °R)}$$

$= 0.075 \ ^{lbm}/_{ft^3}$

3. MASS FLOW RATE

$\dot{m} = \rho A V$

$= (0.075 \ ^{lbm}/_{ft^3})(4.25 \ ft^2)(524 \ ^{ft}/_{min.})$

$= 167.03 \ ^{lbm}/_{min.}$

4. HEAT REMOVED (BTU/min.)

a) SENSIBLE HEAT METHOD

$$Q_{SENSIBLE} = \dot{m}\, C_p (\Delta T)$$

$$= \left(167.03 \ \text{lbm/min}\right)\left(0.24 \ \frac{\text{BTU}}{\text{lbm}\ ^\circ\text{F}}\right)\left(77.6 - 68.0\ ^\circ\text{F}\right)$$

$$= 384.8 \ \text{BTU/min.}$$

$$Q_{LATENT} = \dot{m}\left(\omega_1 - \omega_2\right)\left(1060.5\right)$$

$$= \left(167.03 \ \text{lbm/min.}\right)\left(0.0115 - 0.010 \ \frac{\text{lb}_{H_2O}}{\text{lb}_{DRY\text{-}AIR}}\right)\left(1060.5 \ \text{BTU/lb}_{H_2O}\right)$$

$$= 265.7 \ \text{BTU/min.}$$

$$Q_{TOTAL} = Q_{SENSIBLE} + Q_{LATENT}$$

$$= 384.8 + 265.7 \ \text{BTU/min.}$$

$$= 650.5 \ \text{BTU/min.}$$

b) ENTHALPY OF MIX METHOD

$$Q_{TOTAL} = \dot{m}\left(\Delta h\right)$$

$$= \left(167.03 \ \text{lbm/min.}\right)\left(31.5 - 27.6 \ \text{BTU/lbm}\right)$$

$$= 651.39 \ \text{BTU/min.}$$

5. REFRIGERATION EFFECT

$$\text{TONNAGE} = \frac{Q_{\text{TOTAL}}}{200}$$

$$= \frac{651.39 \ ^{\text{BTU}}/_{\text{min.}}}{200 \ ^{\text{BTU}}/_{\text{TON-min.}}}$$

$$= 3.25 \text{ TONS}$$

II. WATER SIDE

1. MASS FLOW RATE (lbm/min.)

$$\dot{m} = \frac{(\text{FINAL} - \text{INITIAL METER READING})(\rho)}{\text{TIME}}$$

$$= \frac{(49377.2 - 49352.0 \ \text{ft}^3)(62.4 \ \text{lbm/ft}^3)}{30 \ \text{min.}}$$

$$= 51.58 \ \text{lbm/min.}$$

2. ΔT ACROSS CONDENSER $(^\circ\text{F})$

$$\Delta T = T_{OUT} - T_{IN}$$

$$= 84^\circ\text{F} - 70^\circ\text{F}$$

$$= 14^\circ\text{F}$$

3. HEAT REJECTED (BTU/min.)

$$Q_{REJ.} = \dot{m} C_p (\Delta T)$$

$$= (51.58 \ \text{lbm/min.})(1.0 \ \text{BTU/lbm-}^\circ\text{F})(14^\circ\text{F})$$

$$= 722.12 \ \text{BTU/min.}$$

4. COMPRESSOR WORK (W_c)

a) $Q_{ABSORBED}$ (BTU/min.)

$$\frac{Q_{REJ}}{Q_{ABS}} = \text{HEAT REJECTION RATIO}$$

H.R.R. = 1.17 [FROM "STOECKER" Fig. 6-4,
Pg. 99. - CONDENSING TEMP.
@ 125 PSIG ≅ 104-105°F
EVAPORATING TEMP. @ 42 PSIG
≅ 45-46°F]

$$Q_{ABS} = \frac{Q_{REJ}}{H.R.R.}$$

$$= \frac{722.16 \text{ BTU/min.}}{1.17}$$

$$= 617.23 \text{ BTU/min.}$$

b) W_c (BTU/min.)

$$Q_{REJ} = Q_{ABS} + W_c$$

$$W_c = Q_{REJ} - Q_{ABS}$$

$$= 722.16 - 617.23 \text{ BTU/min.}$$

$$= 104.93 \text{ BTU/min.}$$

5. REFRIGERATION EFFECT

$$\text{TONNAGE} = \frac{Q_{ABS}}{200}$$

$$= \frac{617.23 \ \text{BTU/min.}}{200 \ \text{BTU/min.-TON}}$$

$$= 3.08 \ \text{TONS}$$

ALTERNATE METHOD

$$\text{TONNAGE} = \frac{K C_p \dot{V} \rho (\Delta T)}{200}$$

$$= \frac{(0.86)\left(1.0 \frac{\text{BTU}}{\text{lbm-}^\circ\text{F}}\right)\left(24.8 \ \text{ft}^3/\text{min.}\right)\left(62.4 \ \text{lbm}/\text{ft}^3\right)\left(14^\circ\text{F}\right)}{200 \ \text{BTU/min.-TON}}$$

$$= 3.1 \ \text{TONS}$$

III. REFRIGERATION SIDE

1. ENTALPHY ACROSS EVAPORATOR

a) h_{in} (BTU/lbm)

$h_{in} = 26.7$ BTU/lbm @ 125 PSIG & 81.6°F

b) h_{out} (BTU/lbm)

$h_{out} = 82.9$ BTU/lbm @ 42 PSIG & 51.3°F

c) $\Delta h = h_{out} - h_{in}$

$= 82.9 - 26.7$ BTU/lbm

$= 57.2$ BTU/lbm

2. MASS FLOW RATE

a) ROTAMETER CORRECTION FACTOR

$$\text{RATIO OF } \frac{\text{FLOAT DENSITY (316 STNLS)}}{\text{ORIGINAL FLUID DENSITY } (H_2O)} = \frac{532 \text{ lbm/ft}^3}{62.4 \text{ lbm/ft}^3} = 8.52$$

$$\text{RATIO OF } \frac{\text{ORIGINAL FLUID DENSITY } (H_2O)}{\text{NEW FLUID DENSITY (R-12)}} = \frac{62.4 \text{ lbm/ft}^3}{81.25 \text{ lbm/ft}^3} = 0.768$$

FROM CHART → CORRECTION FACTOR =

0.84

b) $\dot{m} = (\text{gal/min.})(\text{ft}^3/\text{gal})(\text{lbm/ft}^3) = \text{lbm/min.}$

$$= \Big[(0.84)(1.5\ \text{gal/min.})\Big]_{R\text{-}12}(0.134\ \text{ft}^3/\text{gal})(81.25\ \text{lbm/ft}^3)$$

$$= 13.7\ \text{lbm/min.}$$

3. REFRIGERATION EFFECT

a) CONSIDERING SUPERHEATED VAPOR @ EVAPORATOR EXIT

$$\text{TONNAGE} = \frac{\dot{m}(\Delta h)}{200}$$

$$= \frac{(13.7\ \text{lbm/min})(57.2\ \text{BTU/lbm})}{200\ \text{BTU/min.-TON}}$$

$$= 3.9\ \text{TONS}$$

b) CONSIDERING SATURATED VAPOR @ EVAPORATOR EXIT

$$\text{TONNAGE} = \frac{(13.7)(55.3)}{200}$$

$$= 3.8\ \text{TONS}$$

Results Sheet

Air Side	
Enthalpy Btu/lb	
Air In	31.5
Air Out	27.6
Density of Air Out lb/cu. ft.	0.075
Corrected Velocity fpm	524
Mass-Flow-Rate lb/min.	167.03
Moisture Content lbv/lb d.a.	
Air In	0.0115
Air Out	0.010
Heat Removed Btu/min	
Total	650.5
Sensible	384.8
Latent	265.7
Refrigeration Effect tons	3.25
Water Side	
Mass-Flow-Rate lb/min.	51.58
ΔT Across Condenser	14
Specific Heat of Water Btu/lb-°R	1.0
Total Heat Rejected Btu/min.	722.12
Compressor Work Btu/min.	104.93
Refrigeration Effect tons	3.08
Refrigeration Side	
Enthalpy Btu/lb	
Evaporator Out	82.9
Evaporator In	26.7
Δh Across Evaporator Btu/lb	57.2
Mass-Flow-Rate lb/min.	13.7
Refrigeration Effect tons	3.9

TAC

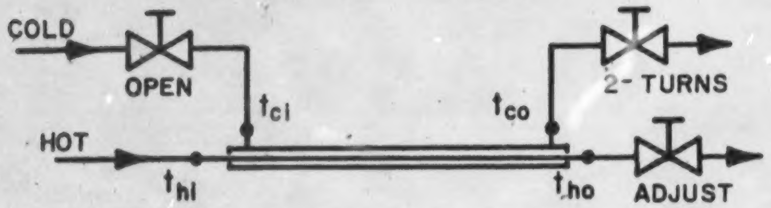
EXPERIMENT NO. 19

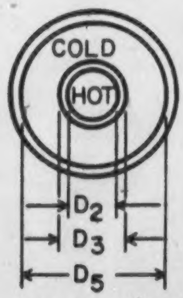
HEAT EXCHANGERS

DATA

EFFECTIVE LENGTH = 25" $D_2 = .305$ $D_3 = .375$ $D_5 = .545$

PARALLEL FLOW

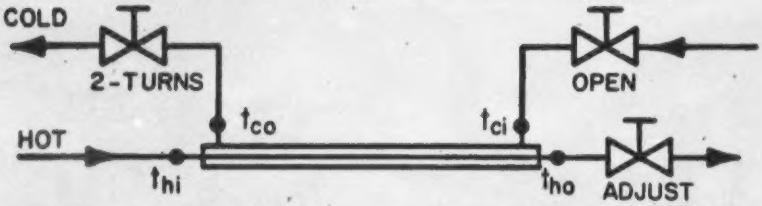

COLD
OPEN
t_{ci}
t_{co}
2- TURNS
HOT
t_{hi}
t_{ho}
ADJUST


COLD
HOT
D_2
D_3
D_5

HOT WATER VALVE (TURNS)	TEMPERATURES (°F)				TIME (MIN.-SEC.)	WEIGHT OF HOT WATER (LB_F) *
	HOT WATER		COLD WATER			
	t_{hi}	t_{ho}	t_{ci}	t_{co}		
1	141.0	122.5	74.5	85.0	6-16	30
	142.5	123.5	74.5	85.5		
1-1/4						
1-1/2	138.0	123.5	74.5	85.5	4-27	30
	139.5	124.5	74.5	86.0		
1-3/4	137.5	124.0	74.0	85.5	5-20	40
	137.0	124.0	74.0	85.5		
2	138.5	125.5	74.0	86.0	3-41	30
	139.0	126.0	74.0	86.5		
2-1/4	136.0	124.0	74.0	85.5	3-28	30
	137.5	126.0	74.0	86.0		
2-1/2	137.5	125.5	73.5	86.0	3-26	30
	135.5	123.5	73.5	85.5		

COUNTER FLOW

* SUGGESTION: COLLECT 30 lb_f IN EACH RUN


COLD
2-TURNS
OPEN
HOT
t_{co}
t_{ci}
t_{hi}
t_{ho}
ADJUST

1	147.0	124.5	75.0	86.0	6-19	30
	149.0	126.0	75.0	86.5		
1-1/4						
1-1/2	145.5	127.5	75.0	87.5	4-26	30
	147.5	129.0	75.0	87.5		
1-3/4	144.0	127.5	75.0	87.5	4-1	30
	145.5	129.0	75.0	88.0		
2	144.5	128.5	75.0	88.0	3-42	30
	144.0	128.5	75.0	88.0		
2-1/4	141.5	127.0	74.5	87.5	3-30	30
	142.5	128.0	75.0	87.5		
2-1/2	146.5	131.0	75.0	88.5	3-21	30
	146.5	131.0	75.0	88.5		

SAMPLE CALCULATIONS

PARALLEL FLOW } COUNTER FLOW

average water inlet and outlet temperatures

hot water in

$t_{hi} = (138.5 + 139.0)/2 = \underline{138.75^\circ F}$ } $(144.5 + 144.0)/2 = \underline{144.25\,^\circ F}$

hot water out

$t_{ho} = (125.5 + 126.0)/2 = \underline{125.75^\circ F}$ } $\underline{128.5\,^\circ F}$

cold water in

$t_{ci} = \underline{74.0\,^\circ F}$ } $\underline{75.0^\circ F}$

cold water out

$t_{co} = (86.0 + 86.5)/2 = \underline{86.25^\circ F}$ } $\underline{88.0^\circ F}$

hot water average temperature

$t_{ha} = (t_{hi} + t_{ho})/2$

$t_{ha} = (138.75 + 125.75)/2 = \underline{132^\circ F}$ } $(144.25 + 128.50)/2 = \underline{136^\circ F}$

hot side temperature drop

$\Delta t_h = t_{hi} - t_{ho}$

$\Delta t_h = 138.75 - 125.75 = \underline{13\,^\circ F}$ } $144.25 - 128.50 = \underline{15.75\,^\circ F}$

cold side temperature rise

$\Delta t_c = t_{co} - t_{ci}$

$\Delta t_c = 86.25 - 74.0 = \underline{12.25^\circ F}$ } $88.0 - 75.0 = \underline{13.0^\circ F}$

inlet temperature difference

$t_{hi} - t_{ci} = 138.75 - 74.0 = \underline{64.75\,^\circ F}$ } $144.25 - 75.0 = \underline{69.25^\circ F}$

terminal temperature differences

$\Delta t_1 = t_{hi} - t_{ci}$ } $\Delta t_1 = t_{hi} - t_{co}$

$\Delta t_1 = 138.75 - 74.0 = \underline{64.75°F}$	$144.25 - 88.0 = \underline{56.25°F}$
$\Delta t_2 = t_{ho} - t_{co}$	$\Delta t_2 = t_{ho} - t_{ci}$
$\Delta t_2 = 125.75 - 86.25 = \underline{39.50°F}$	$128.5 - 75.0 = \underline{53.5°F}$
$\Delta t_1 - \Delta t_2 = 64.75 - 39.50 = \underline{25.25°F}$	$56.25 - 53.5 = \underline{2.75°F}$
$\Delta t_1 / \Delta t_2 = 64.75 / 39.50 = \underline{1.64}$	$56.25/53.5 = \underline{1.051}$
$\ln(\Delta t_1/\Delta t_2) = \underline{.4941}$	$\underline{.0497}$

log mean temperature difference

$\Delta t_{lm} = (\Delta t_1 - \Delta t_2)/\ln(\Delta t_1/\Delta t_2)$

$\Delta t_{lm} = 25.25/.4941 = \underline{51.10°F}$	$2.75/.0497 = \underline{55.33°F}$

mass rate of flow of hot water

$\dot{m}_h = 30.0 \text{ lbm / time}$

$\dot{m}_h = 30.0 \text{ lbm}/(3 \times 60 + 41)\text{sec}$	$30.0 \text{ lbm}/(3 \times 60 + 42) \text{ sec}$
$\dot{m}_h = \underline{.136 \text{ lbm/sec}}$	$\underline{.135 \text{ lbm/sec}}$

heat loss from hot side (=heat gain on cold side)

$\dot{Q} = \dot{m}_h c_{ph} \Delta t_h$

$\dot{Q} = (.136 \text{ lbm/sec})(3600 \text{ sec/h})$ $(1 \text{ Btu/lbm°F})(13.0°F)$	$(.135 \text{ lbm/sec})(3600 \text{ sec/h})$ $(1 \text{ Btu/lbm°F})(15.75°F)$
$\dot{Q} = \underline{6353 \text{ Btu/h}}$	$\underline{7655 \text{ Btu/h}}$

mass rate of flow of cold water

$\dot{m}_c = \dot{Q}/c_{pc} \Delta t_c$

$\dot{m}_c = (6353 \text{ Btu/h})/[(1 \text{ Btu/lbm°F})$ $(12.25°F)]$	$(7655 \text{ Btu/h})/[(1 \text{ Btu/lbm°F})$ $(13.0°F)]$
$\dot{m}_c = \underline{518.6 \text{ lbm/h}}$	$\underline{588.9 \text{ lbm/h}}$

$\dot{m}_c = \underline{.144 \text{ lbm/sec}}$ $\quad$ $\underline{.164 \text{ lbm/sec}}$

average mass rate of flow of cold water

$\dot{m}_{ca} = \left(\sum_{\text{run } 1}^{2} \dot{m}_c\right)/7$

$\dot{m}_{ca} = \underline{522.7 \text{ lbm/h}}$ $\quad$ $\underline{585.9 \text{ lbm/h}}$

$\dot{m}_{ca} = \underline{.145 \text{ lbm/sec}}$ $\quad$ $\underline{.163 \text{ lbm/sec}}$

outside surface area of inner tube

$A_3 = \pi D_3 L$

$A_3 = (3.14)(.375 \text{ in})(25 \text{ in})/144 \text{ in}^2/\text{ft}^2 = \underline{.204 \text{ ft}^2}$

heat transfer rate across area A_3

$\dot{q} = \dot{Q}/A_3$

$\dot{q} = (6353 \text{ Btu/h})/.204 \text{ ft}^2$ $\quad$ $(7655 \text{ Btu/h})/.204 \text{ ft}^2$

$\dot{q} = \underline{31,142 \text{ Btu/h-ft}^2}$ $\quad$ $\underline{37,525 \text{ Btu/h-ft}^2}$

overall mean heat transfer coefficient

$\bar{U}_m = \dot{q}/\Delta t_{lm}$

$\bar{U}_m = (31,142 \text{ Btu/h-ft}^2)/51.1°\text{F}$ $\quad$ $(37,525 \text{ Btu/h-ft}^2)/55.33°\text{F}$

$\bar{U}_m = \underline{609.4 \text{ Btu/h-ft}^2\text{-°F}}$ $\quad$ $\underline{678.2 \text{ Btu/h-ft}^2\text{-°F}}$

capacity ratio

$C_R = (\dot{m} c_p)_{\text{smaller}} / (\dot{m} c_p)_{\text{larger}} = \dot{m}_{\text{smaller}} / \dot{m}_{\text{larger}}$

$\dot{m}_h < \dot{m}_{ca} \quad \therefore \quad C_R = \dot{m}_h / \dot{m}_{ca}$

$C_R = .136/.145 = \underline{.94}$ $\quad$ $.135/.163 = \underline{.83}$

heat exchanger effectiveness

$\epsilon = (t_{hi} - t_{ho})/(t_{hi} - t_{ci}) \quad (\text{if } \dot{m}_h < \dot{m}_{ca})$

$\epsilon = 13.0/64.75 = \underline{.20}$ $\quad$ $15.75/69.25 = \underline{.23}$

thermal properties of the hot fluid based on t_{ha}

$k_1 = .376$ Btu/h-ft-°F	$.377$ Btu/h-ft-°F
$\rho_1 = 61.51$ lbm/ft^3	61.45 lbm/ft^3
$\mu_1 = 1.22$ lbm/ft-h	1.18 lbm/ft-h
$Pr_1 = 3.25$	3.12

cross sectional (fluid flow) area of inner tube

$A_2 = \pi D_2^2/4$

$A_2 = .785\,(.305)^2/144\ ft^2 = \underline{5.071\times10^{-4}\ ft^2}$

velocity of hot fluid in inner tube

$V_1 = \dot{m}_h/\rho_1 A_2$

$V_1 = (488.7\ lbm/h)/[(61.51\ lbm/ft^3)(5.071\times10^{-4}\ ft^2)]$	$(486.5\ lbm/h)/[(61.45\ lbm/ft^3)(5.071\times10^{-4}\ ft^2)]$
$V_1 = \underline{15{,}670\ ft/h}$	$\underline{15{,}615\ ft/h}$
$V_1 = \underline{4.35\ ft/sec}$	$\underline{4.34\ ft/sec}$

Reynolds number for hot water flow

$Re_{D_2} = \rho_1 V_1 D_2/\mu_1$

$Re_{D_2} = (61.51)(15{,}670)(.0254)/1.22$	$(64.45)(15{,}615)(.0254)/1.18$
$Re_{D_2} = \underline{2.01\times10^4}$	$\underline{2.07\times10^4}$
$Re_{D_2}^{.8} = (.201\times10^5)^{.8} = (.201)^{.8}\times10^4$	$(.207)^{.8}\times10^4$
$Re_{D_2}^{.8} = \underline{2.78\times10^3}$	$\underline{2.84\times10^3}$
$Pr_1^{.3} = 3.25^{.3} = \underline{1.42}$	$3.12^{.3} = \underline{1.41}$

Nusselt number for hot water flow

$Nu_{D_2} = .023\, Re_{D_2}^{.8}\, Pr_1^{.3}$

$Nu_{D_2} = (.023)(2.78)(1.42)\, 10^3$	$(.023)(2.84)(1.41)\, 10^3$
$Nu_{D_2} = \underline{90.8}$	$\underline{92.1}$

heat transfer film coefficient on hot side

$h_{12} = Nu_{D_2} k_1 / D_2$

$h_{12} = (90.8)(.376)/.0254$ Btu/h-ft²-°F	$(92.1)(.377)/.0254$ Btu/h-ft²-°F
$h_{12} = \underline{1344}$ Btu/h-ft²-°F	$\underline{1367}$ Btu/h-ft²-°F

heat transfer film coefficient on cold side

$1/h_{34} = 1/U_2 - [D_3 \ln(D_3/D_2)]/2k_{23} - D_3/D_2 h_{12}$

$1/U_2 = 1/609.4$ Btu/h-ft²-°F	$1/678.2$ Btu/h-ft²-°F
$1/U_2 = \underline{.001641}$ h-ft²-°F/Btu	$\underline{.001474}$ h-ft²-°F/Btu

$k_{23} = 223$ Btu/h-ft-°F (copper)

$D_3 \ln(D_3/D_2) = [.375 \ln(.375/.305)/12]$ ft $= \underline{.00647 ft}$

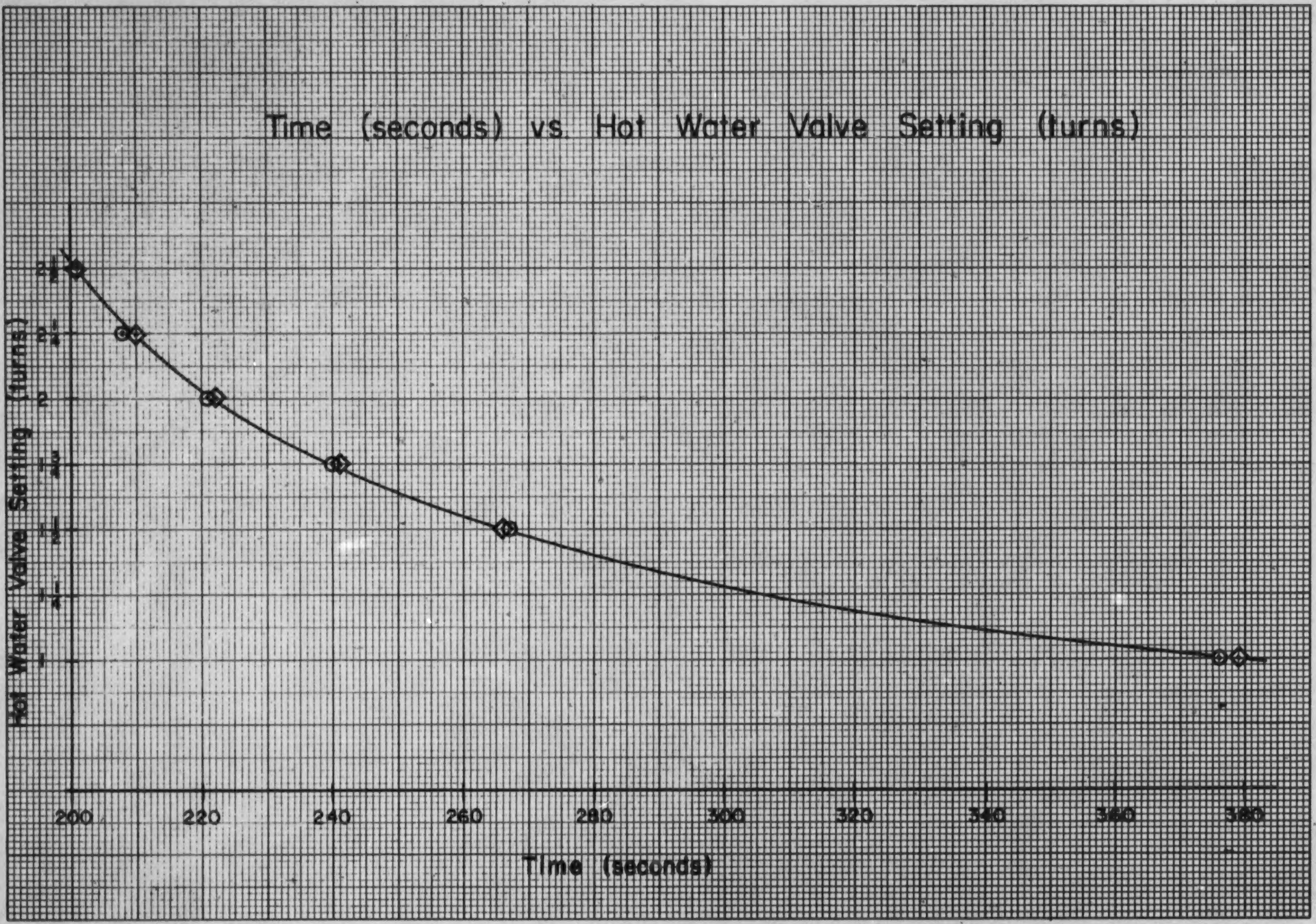
$[D_3 \ln(D_3/D_2)]/2k_{23} = \underline{.000015}$ h-ft²-°F/Btu

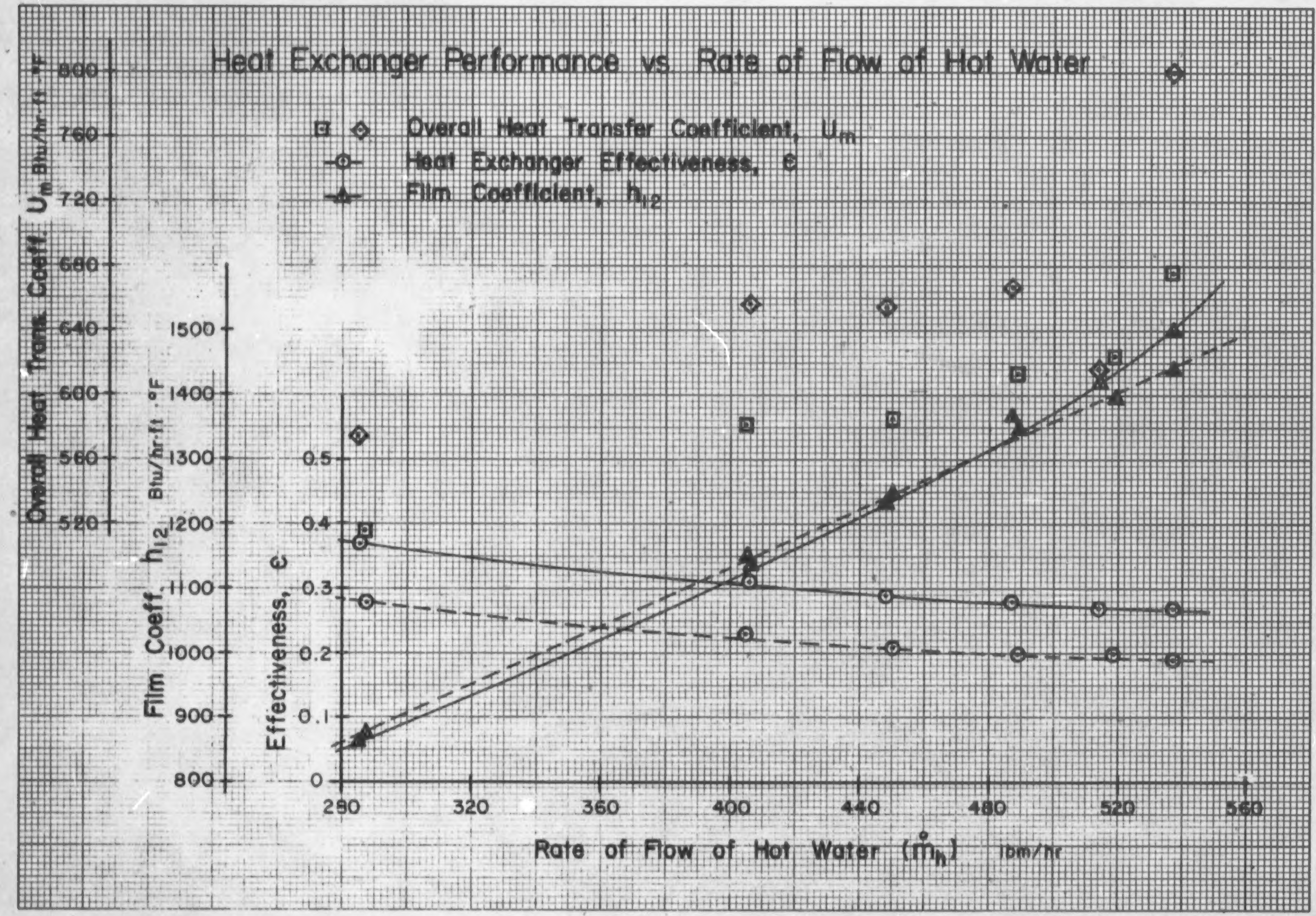
$D_3/D_2 = .375/.305 = 1.23$

$D_3/D_2 h_{12} = 1.23/1344$	$1.23/1367$
$D_3/D_2 h_{12} = \underline{.000915}$ h-ft²-°F/Btu	$\underline{.000899}$ h-ft²-°F/Btu
$1/h_{34} = .000711$ h-ft²-°F/Btu	$.000560$ h-ft²-°F/Btu
$h_{34} = \underline{1406}$ Btu/h-ft²-°F	$\underline{1786}$ Btu/h-ft²-°F

RESULTS

PARALLEL FLOW										
$\dot{m}$ ($^{lbm}/_{hr}$)	t_{ha} (°F)	t_{ca} (°F)	Re @ D_2	Nu @ D_2	Δt_{lm} (°F)	Um $\left(\frac{BTU}{hr-ft^2-°F}\right)$	h_{1-2} ($^{BTU}/_{lbm}$)	h_{3-4} ($^{BTU}/_{lbm}$)	CR	ϵ
287.2	132	80	1.18×10^4	59.11	51.1	516	875	1931	0.55	0.28
404.5	131	80	1.65×10^4	77.95	50.1	584	1151	1590	0.77	0.23
450.0	131	80	1.83×10^4	84.53	50.0	585	1248	1410	0.86	0.21
488.7	132	80	2.01×10^4	90.79	51.0	611	1344	1414	0.93	0.20
519.2	131	80	2.11×10^4	94.72	49.8	626	1398	1422	0.99	0.20
537.3	131	80	2.19×10^4	97.68	49.6	637	1442	1425	0.97	0.19
COUNTER FLOW										
285.0	137	81	1.22×10^4	58.06	55.3	575	862	3333	0.49	0.37
406.0	137	81	1.74×10^4	76.69	55.3	657	1138	2326	0.69	0.31
448.1	137	81	1.92×10^4	83.21	55.4	654	1235	1923	0.76	0.29
486.5	136	82	2.07×10^4	92.10	56.4	666	1367	2000	0.83	0.28
514.3	135	81	2.17×10^4	95.67	59.1	619	1420	1351	0.88	0.27
537.3	139	82	2.34×10^4	100.8	51.0	800	1500	2381	0.92	0.27

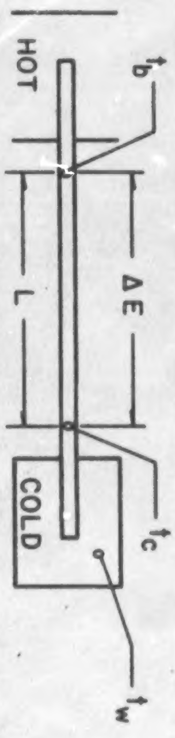

Time (seconds) vs. Hot Water Valve Setting (turns)
Hot Water Valve Setting (turns)
2½
2¼
2
1¾
1½
1¼
1
200
220
240
260
280
300
320
340
360
380
Time (seconds)


Heat Exchanger Performance vs Rate of Flow of Hot Water
⊡ ◈ Overall Heat Transfer Coefficient, U_m
-⊙- Heat Exchanger Effectiveness, ε
-▲- Film Coefficient, h_{12}
Overall Heat Trans. Coeff. U_m Btu/hr-ft · °F
800
760
720
680
640
600
560
520
Film Coeff. h_{12} Btu/hr-ft · °F
1500
1400
1300
1200
1100
1000
900
800
Effectiveness, ε
0.5
0.4
0.3
0.2
0.1
0
280
320
360
400
440
480
520
560
Rate of Flow of Hot Water ($\mathring{m}_h$) lbm/hr

EXPERIMENT NO. 20

METALS AS HEAT CONDUCTORS

DATA



	WEIGHT No. 1	WEIGHT No. 2	WEIGHT No. 3	WEIGHT No. 4	UNITS
WATER	325	325	325	325	ml
BEAKER					
BEAKER & WATER					

ROD No. 1 (IRON)			ROD No. 2 (ALUMN.)			ROD No. 3 (COPPER)			ROD No. 4 (HEAT PIPE)		
Time (sec)	ΔE_1 (mV)	t_{w1} (°F)	Time (sec)	ΔE_2 (mV)	t_{w2} (°F)	Time (sec)	ΔE_3 (mV)	t_{w3} (°F)	Time (sec)	ΔE_4 (mV)	t_{w4} (°F)
0/30	2.44	40	90/120	2.28	43	180/210	1.92	49	0	.35	53
270/300	2.42	41	360/390	2.26	45	450/480	1.86	54	240	.37	67
etc.	2.43	41	etc.	2.23	47	etc.	1.93	58	480	.36	81
	2.52	43		2.33	50		1.81	63	etc.	.33	94
	2.52	44		2.33	53		1.84	68		.30	105
	2.49	45		2.29	56		1.85	73		.30	115
	2.49	46		2.25	58		1.77	77		.28	129
$\Delta\tau$ =	2.47	47	$\Delta\tau$ =	2.22	61	$\Delta\tau$ =	1.72	82	$\Delta\tau$ =	.24	131
270	2.48	48	270	2.22	64	270	1.66	86	240	.19	138
sec	2.45	49	sec	2.20	66	sec	1.64	90	sec	.18	144
	2.44	51		2.15	68		1.56	94		.19	149
	2.39	52		2.10	71		1.49	97		.16	154
	2.38	53		2.08	73		1.47	101		.15	158
	2.37	54		2.05	75		1.45	104		.12	162
	2.33	55		2.01	78		1.38	107		.12	165
	2.30	56		1.99	80		1.35	110		.12	168
	2.27	57		1.99	82		1.29	113		.12	171
	2.25	58		1.94	84		1.27	115		.12	173
	2.22	59		1.90	86		1.15	118		.10	175
	2.18	60		1.72	88		1.24	120		.10	177
	2.21	61		1.86	90		1.18	122		.10	179
	2.20	62		1.82	91		1.14	125		.10	180
	2.17	63		1.80	93		1.11	127		.10	182
	2.17	64		1.78	95		1.06	129		.10	183
	2.15	65		1.75	96		1.05	131		.10	183
	2.15	66		1.76	98		1.02	133		.09	185
	2.13	67		1.74	99		1.02	134		.10	185
	2.12	68		1.69	101		1.01	136		.09	186
	2.10	69		1.65	102		.97	138			

SAMPLE CALCULATIONS

MASS OF COLD WATER IN CUPS

$$325\,\text{ml} = 325\,\text{g} \times .002205\ \text{lbm/g} = \underline{.716\ \text{lbm}}$$

HEAT INPUT TO COLD WATER (COPPER @ $\tau = 80$ min.)

$$Q_W = m_w c_w (t_{w\tau} - t_{w\tau_0})$$

$$= .716\ \text{lbm}\ \frac{1\ \text{Btu}}{\text{lbm}°\text{F}}\ (115 - 49)°\text{F}$$

$$Q_W = \underline{47.3\ \text{Btu}}$$

RATE OF HEAT INPUT TO COLD WATER

$$\frac{\Delta Q_w}{\Delta \tau} = \frac{Q_{w\tau_{n+1}} - Q_{w\tau_n}}{\Delta \tau}$$

$$= \frac{(49.4 - 47.3)\ \text{Btu}}{4.5\ \text{min}}\ \frac{60\ \text{min}}{\text{h}}$$

$$\frac{\Delta Q_w}{\Delta \tau} = \underline{28.0\ \text{Btu/h}}$$

TEMPERATURE DIFFERENCE, Δt BETWEEN THERMOCOUPLES IN THE ROD

$$t_{av\,(rod)} = \frac{t_{hot\ water} + t_{cold\ water}}{2} \qquad \text{(assumed)}$$

$$t_{av\,(rod)} = \frac{(212 + 115)°\text{F}}{2} = 164°\text{F}$$

$$E_{av\,(rod)} = 3.06\ \text{mV}$$

$$E_{hot} = E_{av} + \frac{\Delta E}{2} = 3.06 + \frac{1.28\ \text{mV}}{2} = 3.70\ \text{mV}$$

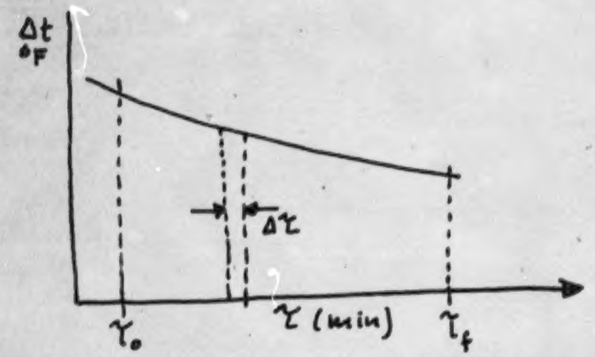
$$t_{hot} = \underline{190°\text{F}}$$

$$E_{cold} = E_{av} - \frac{\Delta E}{2} = 3.06 - .64\ \text{mV} = 2.42\ \text{mV}$$

$$t_{cold} = \underline{138°\text{F}}$$

$$\Delta t = t_{hot} - t_{cold} = (190 - 138)°\text{F} = \underline{52°\text{F}}$$

EVALUATION OF $\int_{\tau_0}^{\tau_f} \Delta t \, d\tau$



approximate area under the curve

$$\sum_{n=0}^{f-1} \Delta\tau \left(\frac{\Delta t_{\tau_n} + \Delta t_{\tau_{n+1}}}{2}\right) = \Delta\tau \sum_{n=0}^{f-1} \frac{\Delta t_{\tau_n} + \Delta t_{\tau_{n+1}}}{2}$$

$$\int_{\tau_0}^{\tau_f} \Delta t \, d\tau \approx 112.6 \text{ °F-h}$$

HEAT ADDED TO WATER DURING TIME $\tau_f - \tau_0$

$$Q_w = m_w c_w \left(t_{\tau_f} - t_{\tau_0}\right)$$

$$= .716 \text{ lbm } \frac{1 \text{ Btu}}{\text{lbm °F}} \left(142 - 63\right) \text{°F}$$

$$Q_w = \underline{56.6 \text{ Btu}}$$

ESTIMATED CONDUCTIVITY

$$k \approx \frac{L\, Q_w}{A \int_{\tau_0}^{\tau_f} \Delta t \, d\tau}$$

$$L = \frac{3.5}{12} \text{ ft} = .292 \text{ ft}$$

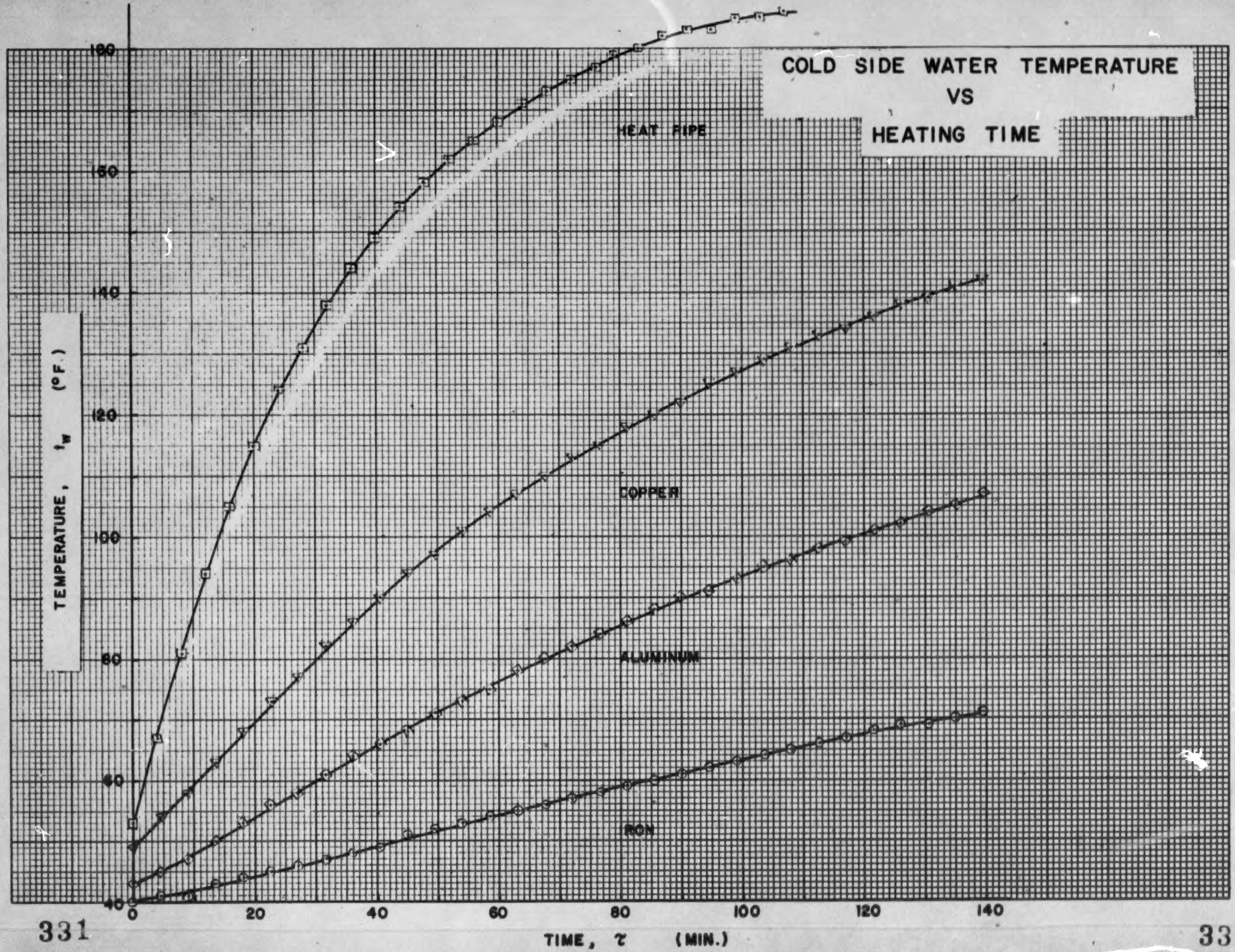
$$A = \frac{(.375)^2(.785)}{144} \text{ ft}^2 = .000767 \text{ ft}^2$$

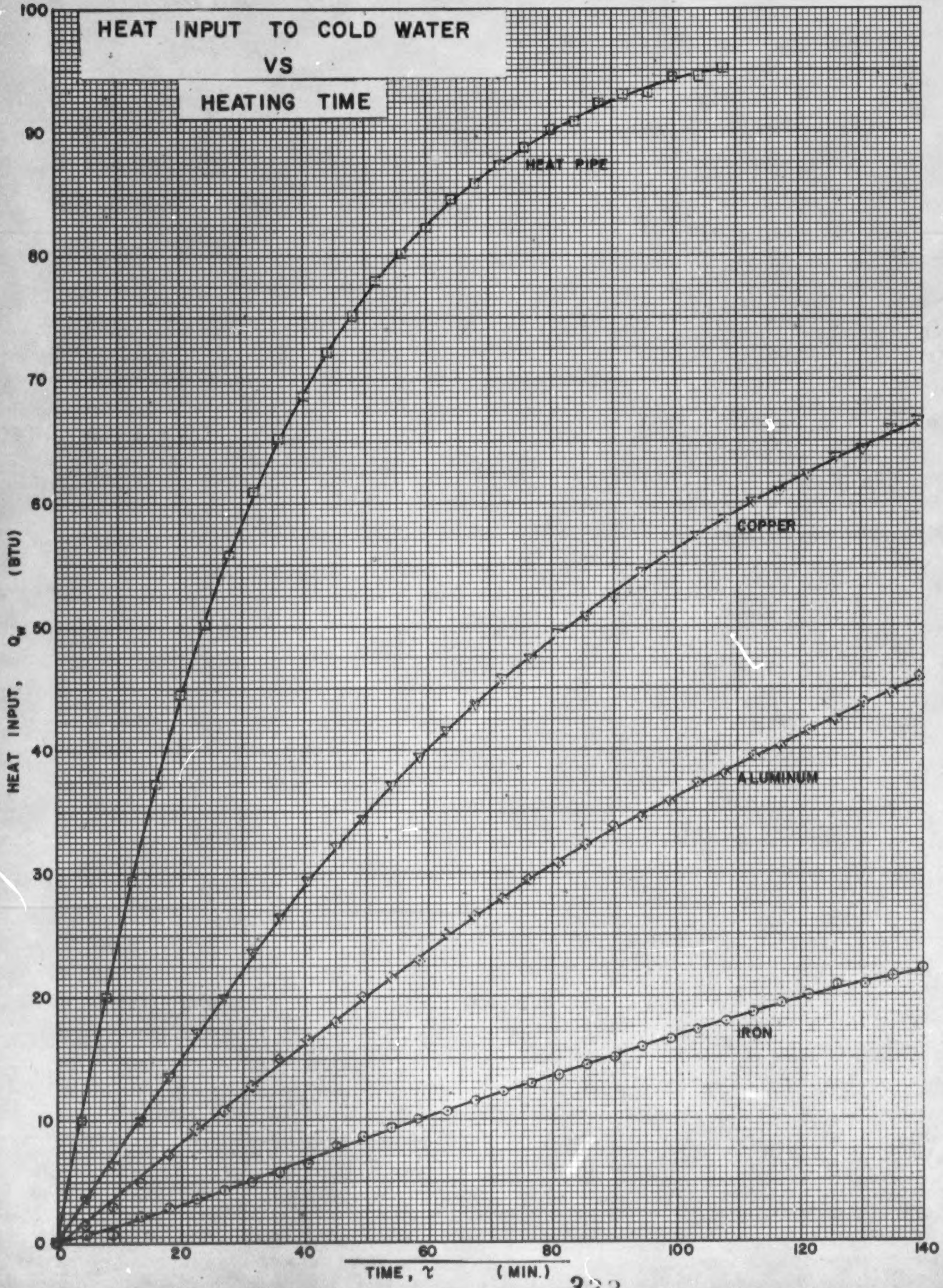
$$k = \frac{.292\ \text{ft}\quad 56.6\ \text{Btu}}{.000767\ \text{ft}^2\quad 112.6\ ^\circ\text{F-h}}$$

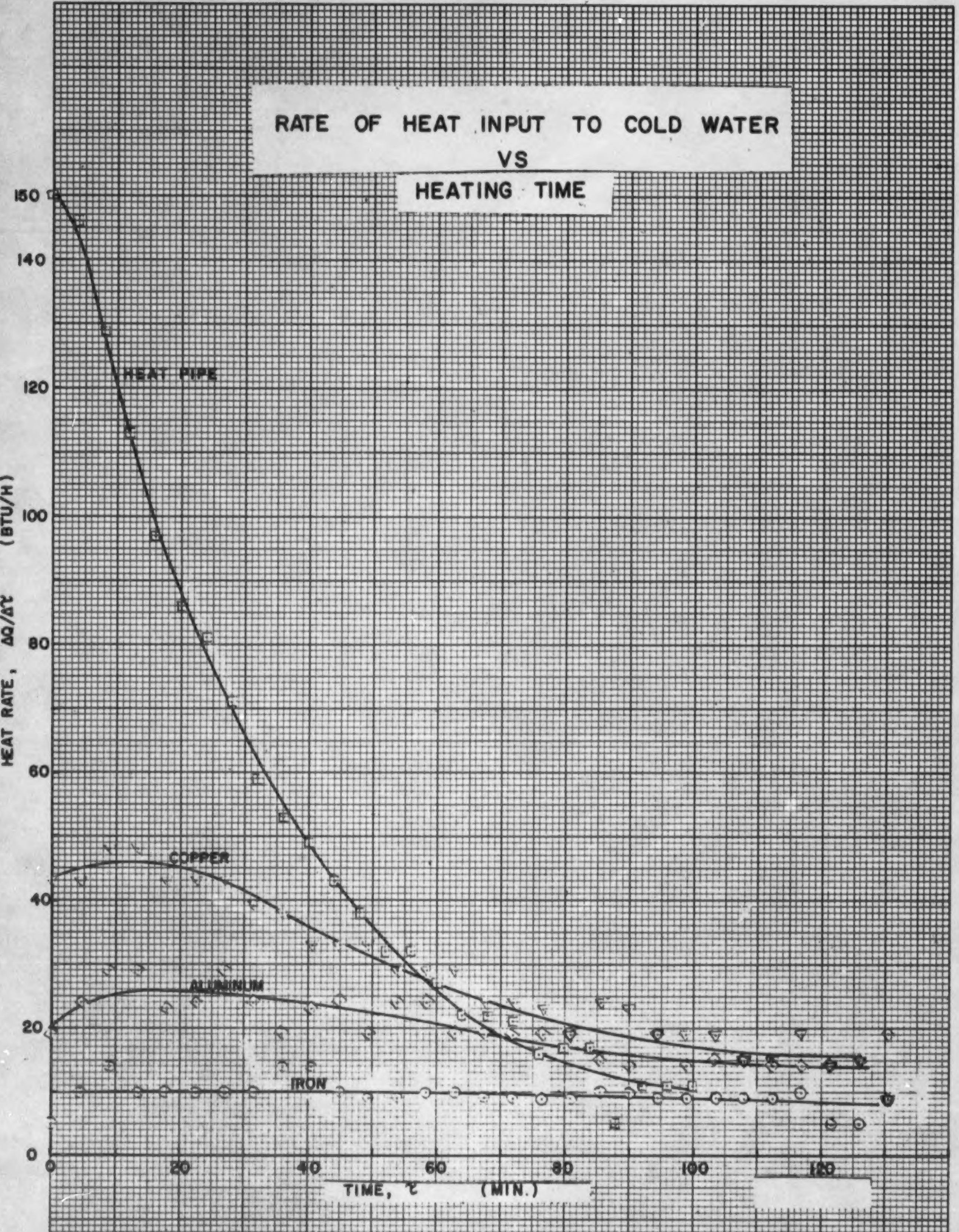
$k =$	191	Btu/hr·ft·°F	(COPPER)
	23	"	(IRON)
	79	"	(ALUMINUM)
	2558	"	(EQUIVALENT CONDUCTIVITY FOR HEAT PIPE)

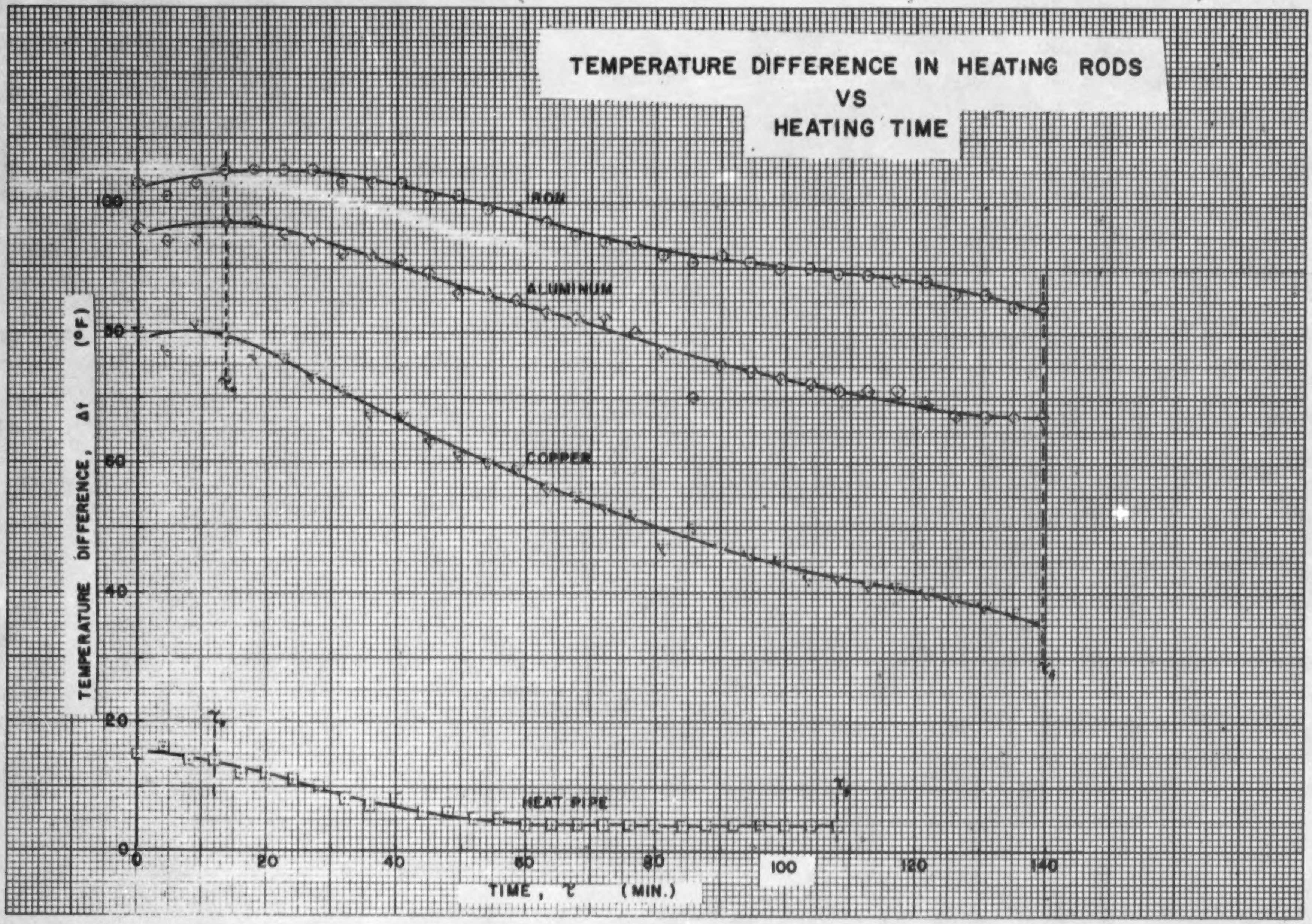
RESULTS

No. 1 (IRON)		No. 2 (ALUMN.)		No. 3 (COPPER)		No. 4 (HEAT PIPE)	
MASS OF WATER .716 lb_m		MASS OF WATER .716 lb_m		MASS OF WATER .716 lb_m		MASS OF WATER .716 lb_m	
Time (sec)	Δt_1 (°F)	Time (sec)	Δt_2 (°F)	Time (sec)	Δt_3 (°F)	Time (sec)	Δt_4 (°F)
0	103	90	96	180	80	0	15
270	101	360	94	450	77	240	16
540	103	630	94	720	81	480	14
etc.	105	etc.	97	etc.	79	etc.	14
	105		97		76		12
$\Delta\tau$ =	105	$\Delta\tau$ =	95	$\Delta\tau$ =	76	$\Delta\tau$ =	12
270	105	270	94	270	73	240	11
sec	103	sec	92	sec	71	sec	10
	103		92		67		8
	103		91		67		7
	101		89		63		8
	101		86		61		6
	99		86		60		6
	99		85		59		5
	97		83		56		5
	95		82		55		4
	94		82		53		4
	94		80		52		4
	92		77		47		4
	91		70		50		4
	92		75		47		4
	91		74		46		4
	90		73		45		4
	90		72		42		4
	89		71		42		4
	89		71		41		4
	88		71		41		4
	88		69		40		4
	86		67		39		

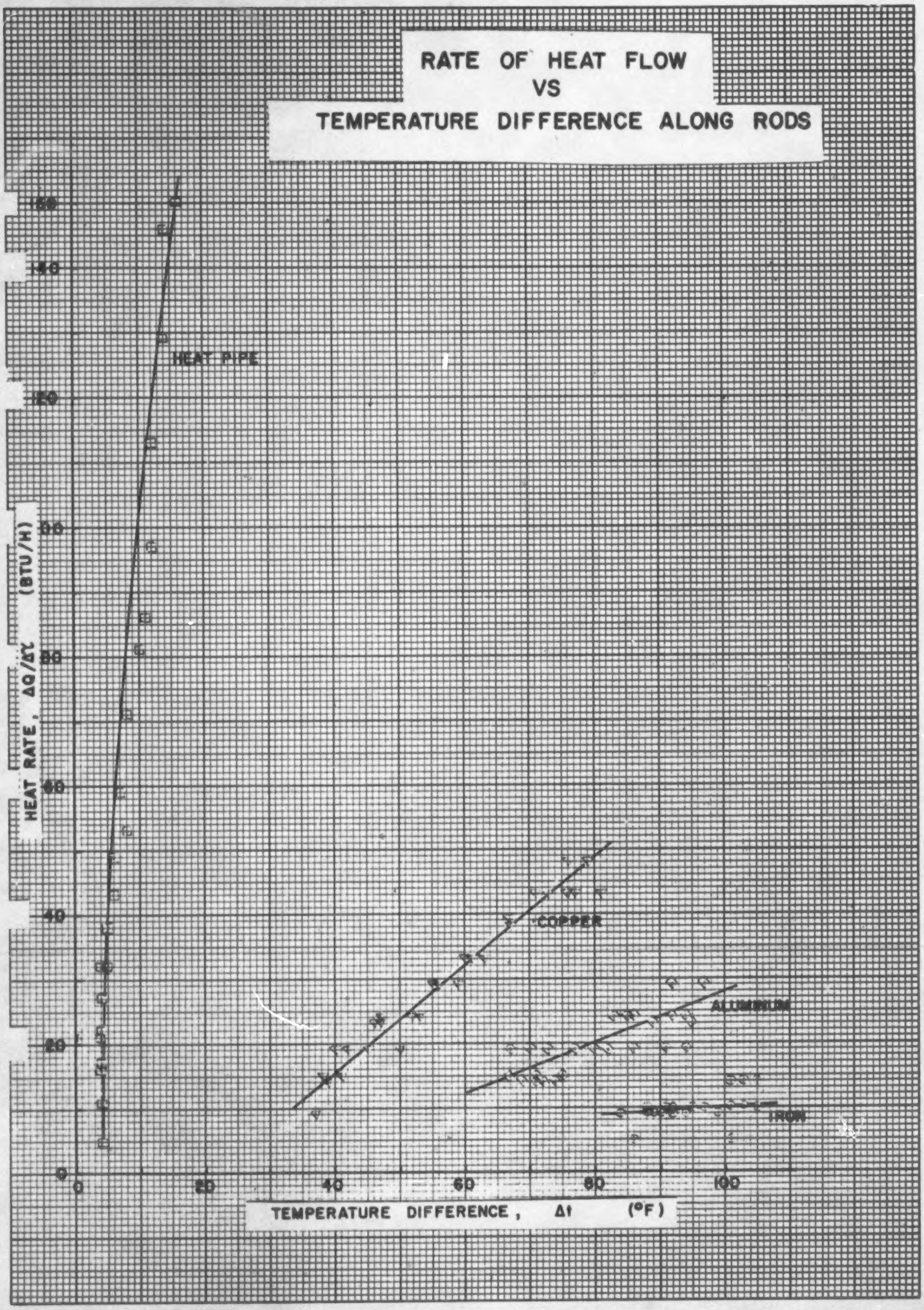

COLD SIDE WATER TEMPERATURE
VS
HEATING TIME
HEAT PIPE
COPPER
ALUMINUM
IRON
TEMPERATURE, t_w (°F.)
TIME, τ (MIN.)
40
60
80
100
120
140
160
180
0
20
40
60
80
100
120
140


HEAT INPUT TO COLD WATER
VS
HEATING TIME
HEAT PIPE
COPPER
ALUMINUM
IRON
HEAT INPUT, Q_w (BTU)
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
TIME, τ (MIN.)


RATE OF HEAT INPUT TO COLD WATER
VS
HEATING TIME
HEAT PIPE
COPPER
ALUMINUM
IRON
HEAT RATE, ΔQ/Δτ (BTU/H)
150
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
TIME, τ (MIN.)



TEMPERATURE DIFFERENCE IN HEATING RODS
VS
HEATING TIME


RATE OF HEAT FLOW
VS
TEMPERATURE DIFFERENCE ALONG RODS